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HUMAN ENGINEERING ANALYSIS OF THE AUGMENTED FOUR-WHEELS SYSTEM

by

George Grant, Robert B. King and Stephen H. Gates

1 March 1962

HRB-Singer, Inc.
State College, Pennsylvania

Final Report

Contract Number AF19(604)-7990
Project No. 431L/482L
Systems No. 2124
Task No. 46518

Prepared for

ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH

and

OPERATIONAL APPLICATIONS LABORATORY
DEPUTY FOR TECHNOLOGY
AIR FORCE ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

HRB

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FOREWORD

This report is based on HRB-Singer's effort on Contract No. AF 19(604)-7990. The work has been focused on development of the human engineering requirements for the tower, communications, IFR approach control and radar portions of the ANITSQ-47 System. Future efforts should provide for proficiency, controller aid, and maintenance shelters.

Acknowledgment is made for the assistance and cooperation of Ben Greene, James B. Cawley, M/Sgt. Henry Spiewak, SM/Sgt. Richard D. Lewis, and Harvey H. Weiner of the Control Sciences Laboratory. The authors also acknowledge the guidance and cooperation of Dr. John Coules of the Operational Applications Laboratory.

ABSTRACT

This report is a description of the human engineering aspects of the IFR, Precision Approach Radar (PAR), Airport Surveillance Radar (ASR), Communications and VFR Tower shelters of the ANITSQ-47 System. It describes the layout, equipment configurations, operational functions and ambient conditions for each of these shelters.

The final sections outline human engineering recommendations for common aspects of the system and recommendations for future efforts on the system.

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I. SUMMARY

This report details the work performed by HRB-Singer, Inc., under Contract AF 19(604)-7990. This contract, which covered the period of 15 January, 1961 to 15 January, 1962 called for human engineering analyses of the "Augmented Four-Wheels" Mobile Air Traffic Control System (subsequently designated as the AN/TSQ-47 System). During this time period, HRB-Singer studied all aspects of the proposed system which involved any type of man-machine interaction, and acted as a general human engineering consultant to the Air Force personnel responsible for the preparation of system specifications.

The AN/TSQ-47 was conceived as an interim system, consisting of readily available (off-the-shelf) equipments and components which could be assembled into a system within one year. Its purpose is to provide the Air Force with a mobile communications, air traffic control, and navigation (with the AN/TRN-17 as GFE) capability for use in emergency or for special tactical situations.

The program was carried out primarily by HRB-Singer personnel located at the Control Sciences Laboratory of the Air Force Cambridge Research Laboratory. It emphasized the following human engineering goals:

1. Specification of acceptable ambient work environments,
2. Proper allocation of functions to man and equipment,
3. Design of shelter layouts for efficient operation and information flow,
4. Design of individual workspaces in terms of space, location of components, selection of controls, displays, and console configuration,
5. Design for ease and efficiency of setting up, operating and in maintenance by personnel of skill levels available to the Air Force.

Primary effort under this contract was concerned with the five operational subsystems designated for initial procurement. These included the (1) Communications, (2) IFR, (3) Tower, (4) Surveillance Radar, and (5) Precision Approach Radar Shelters. Also, preliminary consideration was given to subsequent portions of the system which consist of a maintenance facility and shelter, a proficiency check out shelter, and possibly a controller -aid shelter.

This report describes the AN/TSQ-47 system from the human engineering viewpoint and discusses the rationale for the recommendations and suggestions which were incorporated into the system design. Section II includes human engineering recommendations which are pertinent to all shelters, primarily in the area of ambient environments. Section III describes each of the five shelters listed above in terms of its layout, communication capabilities, operator functions, and man-machine interfaces. These five operational shelters are discussed in greater detail since these portions of the system have been fully specified in complete detail and have been subjected to intensive study by both engineering and human engineering specialists. Section IV lists some of the major design features which are important in attaining a standardized and integrated system, while Section V outlines future requirements necessary to complete the system and suggests areas for further study effort in respect to the projected support-type shelters. The appendix describes the program management, manpower expended and travel incurred during the course of the contract.

II. SYSTEM-WIDE HUMAN ENGINEERING

A. INTRODUCTION

From the standpoint of human engineering, the two most important system-wide problem areas are the provision of adequate ambient environments in each shelter, and the standardization components, configurations, and coding procedures for equipment or functions common to more than one shelter.

Unfavorable environmental conditions can cause severe degradations in human performance of the type required for operation of the AN/TSQ-47 system. In addition to the detrimental effects upon visual and auditory transmission of information, an unfavorable or inadequate environment can cause discomfort, nausea, and fatigue, and can result in severe decrements in vigilance, discrimination, and reasoning tasks. The environmental conditions of prime importance to this system include noise, illumination, air temperature, humidity, and air velocity. Each of these may be described in terms of maximum levels or tolerance ranges. The table below summarizes the recommendations in this regard.

Condition	External	Internal
Noise	100 db max. (at source)	70 db desirable 80 db max.
Temperature		65-80°F
Relative Humidity		40-60%
Air Velocity		75 ft/min max.

The following sections elaborate upon the various problems encountered in each of these environmental conditions and discuss some applicable solutions to these problems in terms of the AN/TSQ-47 system.

B. NOISE LEVELS

The control and reduction of noise from sources such as power generators, air conditioners, rotating antennas, aircraft engines, and human conversations will be one of the major problems in the mobile AN/TSQ-47 complex. An internal ambient noise level of 70 db (with all equipment operating and with normal operation in progress) should permit efficient human performance. When noise levels exceed these values, voice communications intelligibility deteriorates, resulting in information loss and/or time delays, overburdening of communication channels, operator strain and possible fatigue.

While relative quiet (i. e. in the neighborhood of 50 db) would certainly be beneficial in terms of operational efficiency, it is not at all certain that such low levels can be achieved within the AN/TSQ-47. The specified noise curve for the power generators averages approximately 80 db across the speech spectrum at a distance of 20 feet. Since the generators will be at about that distance from the shelters,and the attenuation through the shelter walls (with the door closed) is in the neighborhood of 12 db*, a further reduction in noise levels (below about 70 db) would necessitate additional acoustic shielding which would in turn increase the weight of the shelter and decrease the interior space. This problem will require further study by cognizant Air Force personnel who will have to make the trade-off decision.

In the light of the available research data relating to noise levels and speech intelligibility **, which indicate that levels up to 70 db do not cause serious deterioration in speech reception, it seems feasible to recommend a maximum interior noise level of 70 db as a design objective. Since the sound level of normal voice communications is typically below this level, it will not result in further appreciable increase in noise level.

Unfortunately, the noise problem is compounded in both the IFR and Communications shelters. Both of these shelters must rely heavily upon voice communications but, because of their power and heat dissipation requirements, they will require multiple generators and air conditioners and thus further complicate the noise reduction effort.

In general terms, the amount of noise produced can be reduced by careful modification of equipment, use of vibration mountings, proper maintenance and repair of equipment cases and ducting systems, and the use of mufflers and baffles. The

*Based on data collected by HRB-Singer Human Factors personnel at Tinker AFB and Craig Systems, Inc., Lawrence, Mass., on Contract AF 19(#04)-7990.

**Peterson, A. P., and Beranek, L. L. Handbook of Noise Measurement. General Radio Co., Cambridge, Mass., 1954.

transmission of noise, on the other hand, can be reduced by remoting the prime noise sources (e.g., power generators), the use of acoustical shielding on shelter walls and ceilings, and soundtreating of individual work areas. Where it is not possible to attain tolerable noise levels (e.g., for maintenance men working on antenna masts or shelter exteriors) noise shielded earphones and/or protective plugs should be provided.

C. ILLUMINATION

The desirable ranges of illumination will vary somewhat from shelter to shelter, and even within a given shelter depending on the specific operator functions. The AN/TSC-23 communications shelter will have little trouble in this regard since uniform high intensity lighting (25-30ft. candles) will be adequate for all tasks. The AN/TPS-35 (ASR) and AN/TPN-14 (PAR) shelters should have adjustable illumination over a wide range (2-30ft. candles) to permit a corresponding range of functions, from actual use of the CRT in controlling aircraft, to checkout and maintenance.

The major illumination problems will occur in the AN/TSW-6 Tower and AM/TSW-5 IFR shelters. The Tower shelter will, of course, require a transparent glass enclosure to provide complete external visibility. The main illumination problems encountered in such a configuration will be the use of lighting which is flexible enough to permit sufficient visibility, without glare, under daylight conditions and still prevent loss of dark adaptation during night operations. This will require the use of edge lighting and/or red light filters and the capacity for light shields to screen off the data position which will require greater levels of illumination.

The IFR shelter will present other illumination problems. The light levels must be low enough to permit operation of the CRT indicators and yet still permit the controllers to record and read data and operate communications equipment. The exact levels of illumination specified for areas adjacent to CRT displays will be dependent upon the measurement of the light outputs of the CRT displays selected. It may be desirable to consider the use of some method of polarization filtering or light shielding to prevent ambient illumination from deteriorating controller performance on CRT displays.

Lighting for maintenance operations must also be considered throughout the system. The human engineering effort will outline the requirements for convenience receptacles where maintenance must be required, and the provision of maintenance and trouble shooting lights in applicable consoles.

Other lighting considerations might include exterior shelter lights for identification at night, and lighting for ground areas between shelters for personnel safety during non-tactical peacetime deployments.

D. AIR TEMPERATURE, HUMIDITY, AND VELOCITY

In order to prevent undue fatigue and performance decrements, the temperature inside the shelter should range between 65° and 75° and the humidity between 30 and 70 per cent. In deployments to extreme tropical areas, the upper temperature limits may be raised somewhat, but not in excess of 85°, the point at which complex performance begins to deteriorate markedly.

In relatively small shelters such as those to be used in the AN/TSQ-47 system, the problem of providing sufficient air circulation for cooling purposes, without causing extreme drafts and air "blasts" in the operator work areas, must also be considered. Each operator will require 4 to 5 cu. ft. / min. of fresh air ventilation just to prevent the accumulation of carbon dioxide -- requirements for maintaining effective levels of temperature and humidity dictate air exchange at the rate of 35 - 40 cu. ft./ min. If the maximum air velocity exceeds 60-70 ft./ min., distinct drafts occur and it may be necessary to split the air flow necessary for cooling of the equipment from that ducted to the operator compartments and to provide a multiple venting system in order to reduce the total velocity within the work area. One means of producing such a multiple air flow would be through the use of perforated false ceilings which would act as a plenum chamber. The air would be ducted into this chamber and then forced through the perforations to create an even, diffused air flow.

E. STANDARDIZATION OF SHELTERS

The preparation of the original "Four-Wheels" system for transport and operation was extremely difficult and time-consuming. In order to prevent the recurrence of such shortcomings, the shelter configurations should be standardized with regard to access to stored materials, antenna mounts and pedestals, equipment coding and labeling, stabilizing jacks, dollies and hoists, etc., wherever possible. The setup procedures and sequences should also be standardized in order to minimize the time and difficulty involved in readying the system for operation. A general discussion of common design criteria is presented in Section IV of this report.

One other important requirement for standardization concerning the PAR and ASR shelters should be stressed at this point. Since it is envisioned that the CRT indicator in these shelters can also be used to form an auxiliary controller station (for back-up purposes or when these shelters are deployed as individual units), it would be desirable to standardize the console layout for each shelter and its respective remote indicator in the IFR. This will insure transfer of response habits when an experienced operator is required to shift between the IFR and the radar shelters.

III. INDIVIDUAL SHELTER DESCRIPTIONS

A. INTRODUCTION

This section provides a description of the human engineering aspects of the several subsystem shelters which make up the AN/TSQ-47 system. The descriptions of the five operational shelters are more complete since these have been studied in detail and procurement action has been initiated. The discussions of the maintenance and proficiency check-out facilities are at a more general level since these shelters (Sections G, H, and I), are still under study by both the Air Force and HRB-Singer.

Each of the five operational shelters (the Communications, IFR, Tower, Surveillance Radar, and PAR subsystems) are described in terms of layout, communications capabilities, and operator functions. Where necessary these descriptions are supplemented by supporting data, the rationale for selection of a given alternative, and/or a discussion of the problems involved.

The AN/TRN-17 (TACAN) shelter is not discussed since this will be Government furnished equipment and will not undergo redesign. Some details of the KW-26 cryptographic equipment have likewise been omitted for reasons of security.

B. COMMUNICATIONS CENTRAL, AN/TSC-23

1. Shelter Layout

In the process of locating all of the equipment necessary to insure communications capabilities, many workspace compromises were required. The provision of adequate operator workspace has been one of the prime human engineering problems in this shelter.

Figures 1, 2, and 3 show the equipment layout, along with the five possible operator positions.

The shelter layout was determined, in part, by the communication flow through the communication center. Figures 4, 5, and 6 show the flow for Encrypted teletype, Teletype (in-the-clear), and Voice radio, respectively, while Figure 7 shows a composite flow for all of these functions.

The layout of equipment described here offers the best solution to workspace problems. One serious problem remains, however: pull-out space for the KW-26 cryptographic unit shown in Figure 1. The KW-26 units are 26 inches long, and the pull-out space is 28 inches. The problem is further complicated by the fact that this unit weighs approximately 100 pounds. Current plans call for a dolly to assist in the removal of this unit for maintenance.

Heat problems were also considered in the design of the shelter layout The equipments generating the most heat (the two KW-26 units and the radio equipment rack) were located across the back wall (opposite wall from the door) to improve the air conditioning efficiency

All cryptographic messages that are transferred between the communication shelter and the base must be hand carried and routed through operator position 1. This position has therefore been located just inside the shelter door in order to reduce the personnel traffic inside the shelter.

The shelter configuration also includes a separate 20-line switchboard. This will normally be set up in a tent outside of the shelter whenever it is needed. It will be used as a telephone central for the land lines in each shelter and will connect with the base telephone exchange. The switchboard will be stored inside the shelter during transit.

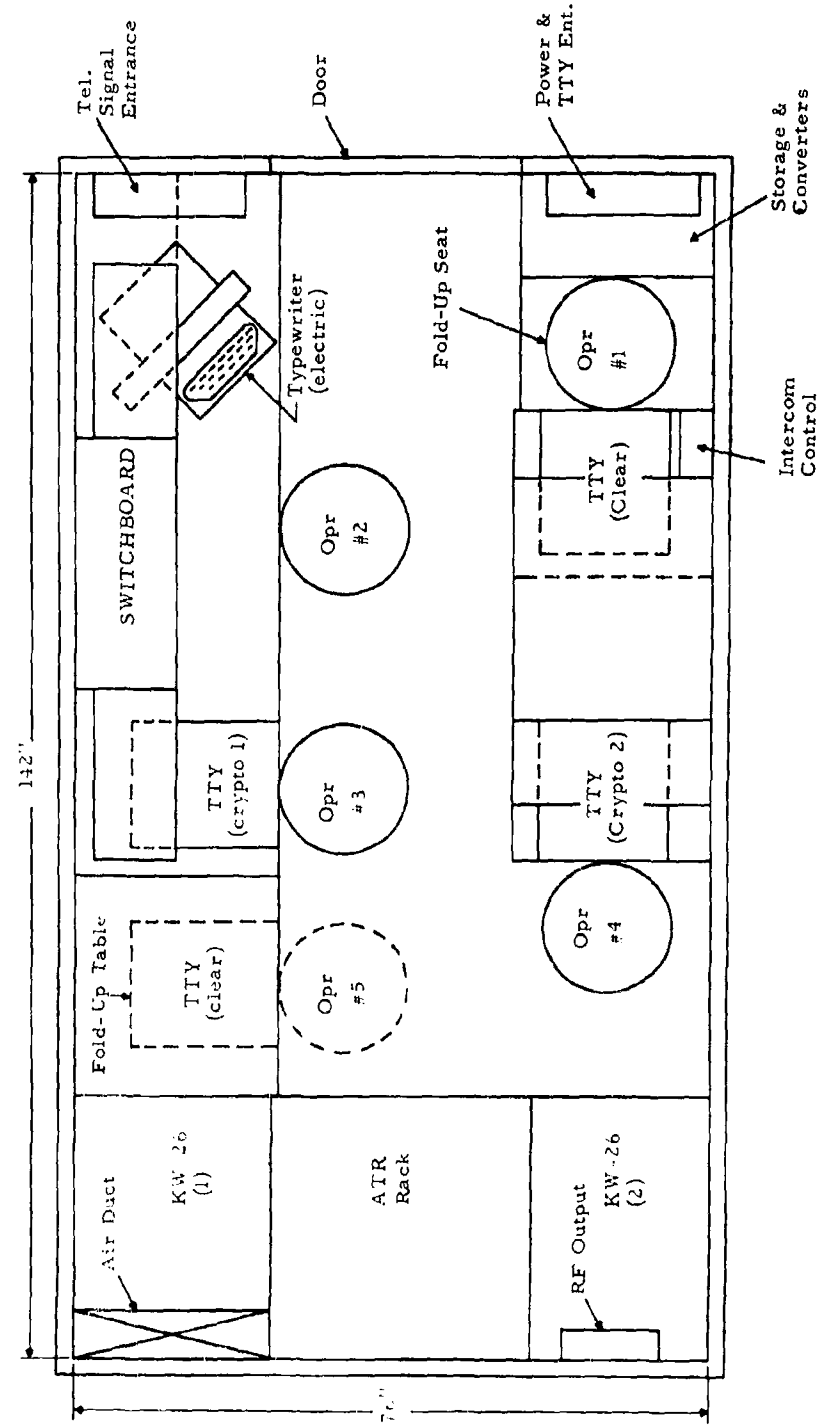


Fig. 1 - Communications Shelter, Floor Plan

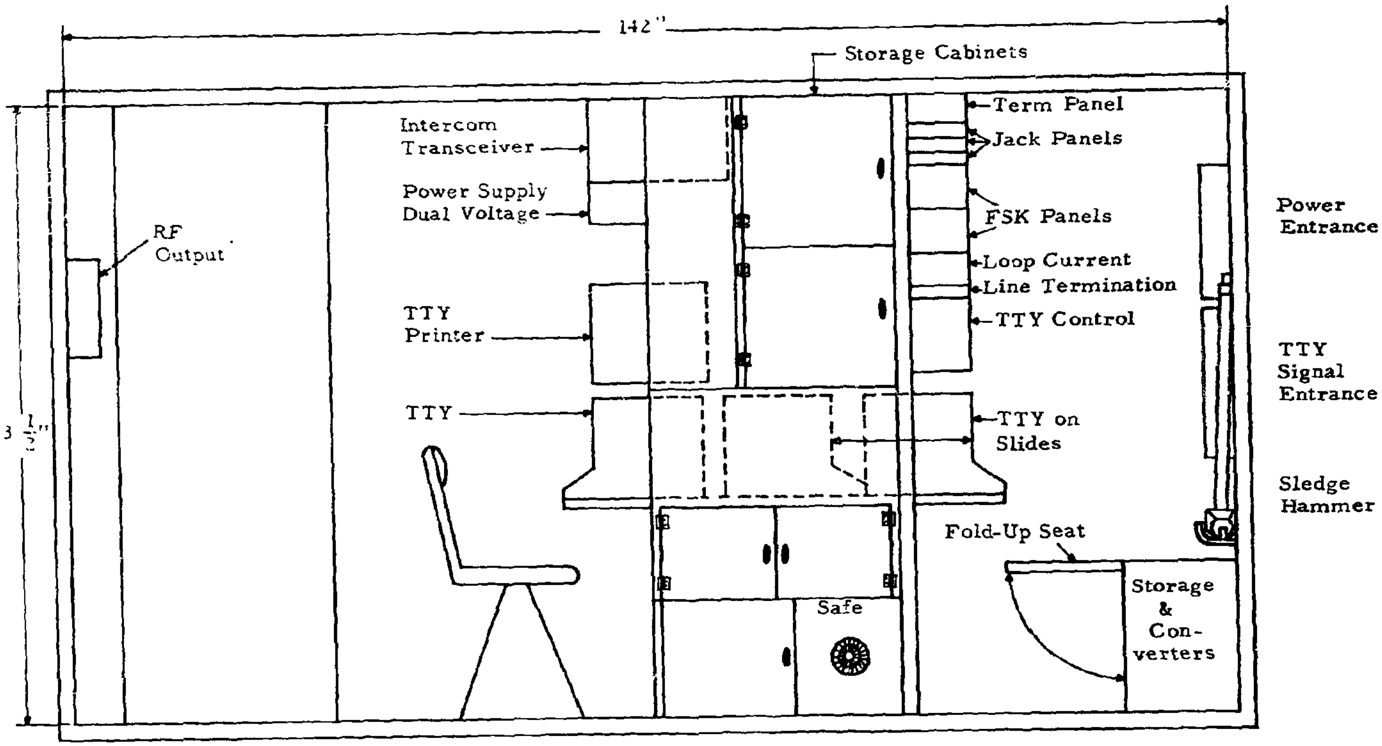


Fig. 2 - Communications Shelter, Left Side View

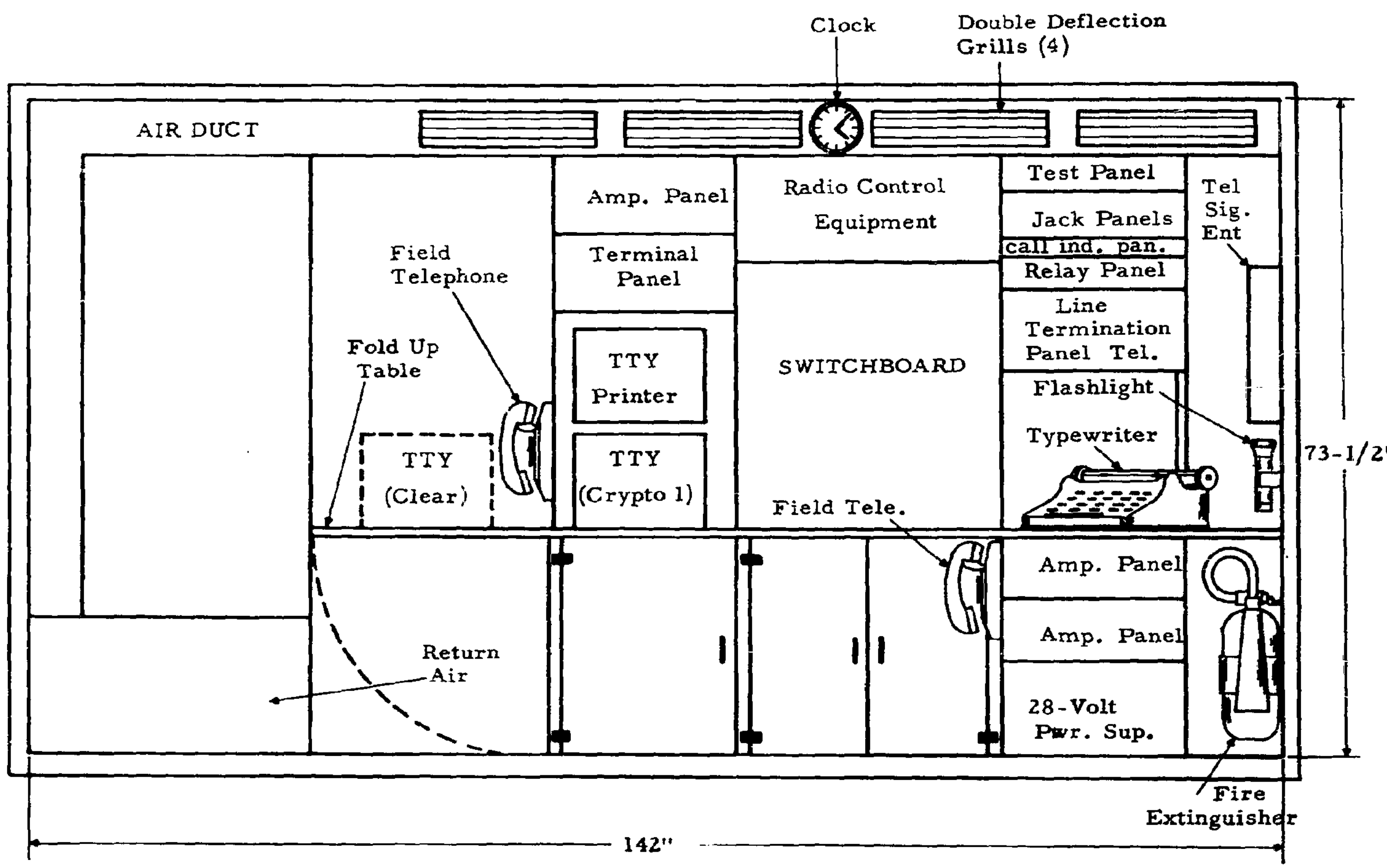


Fig.3-Communications Shelter, Right Side View

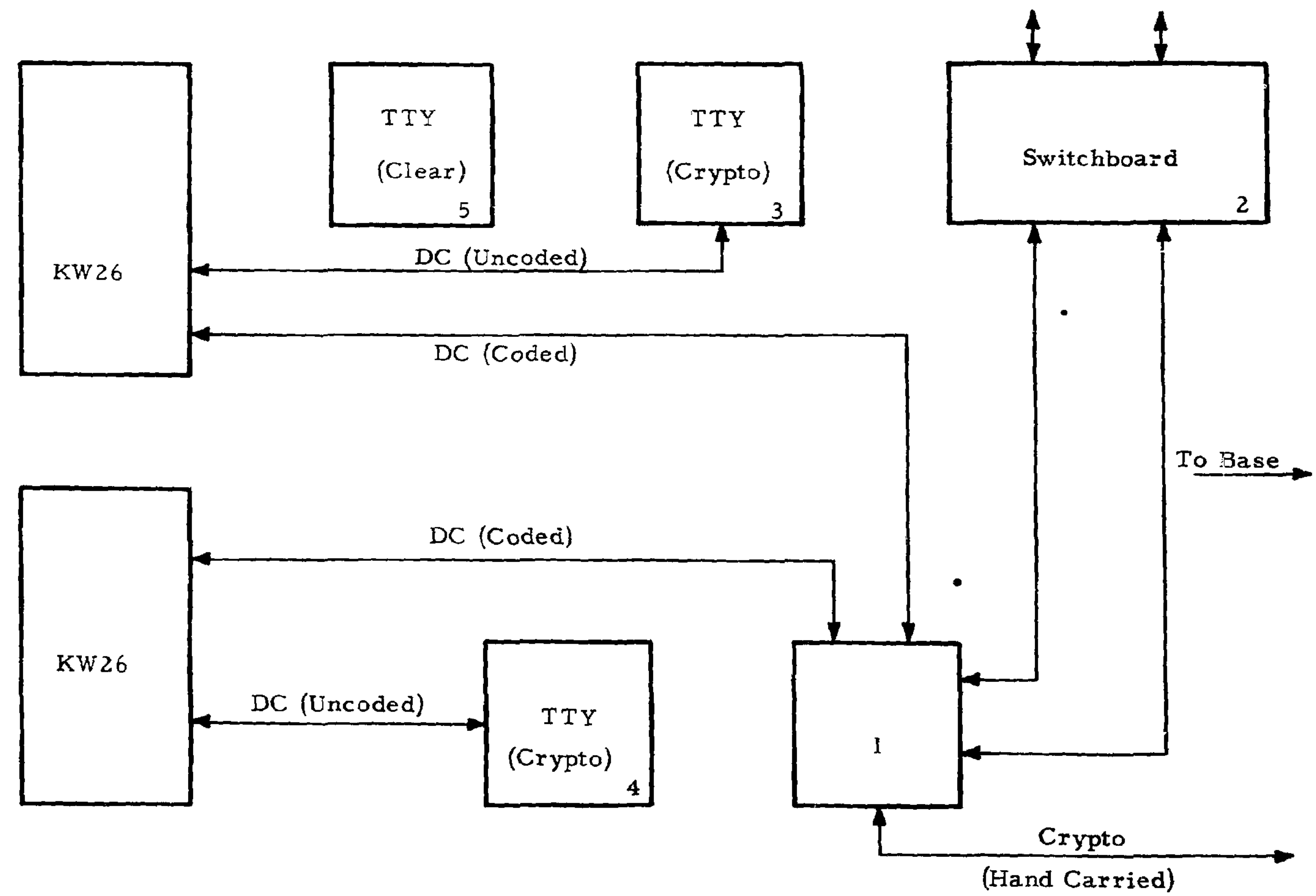


Fig. 4 - Crypto Communications Flow Diagram.

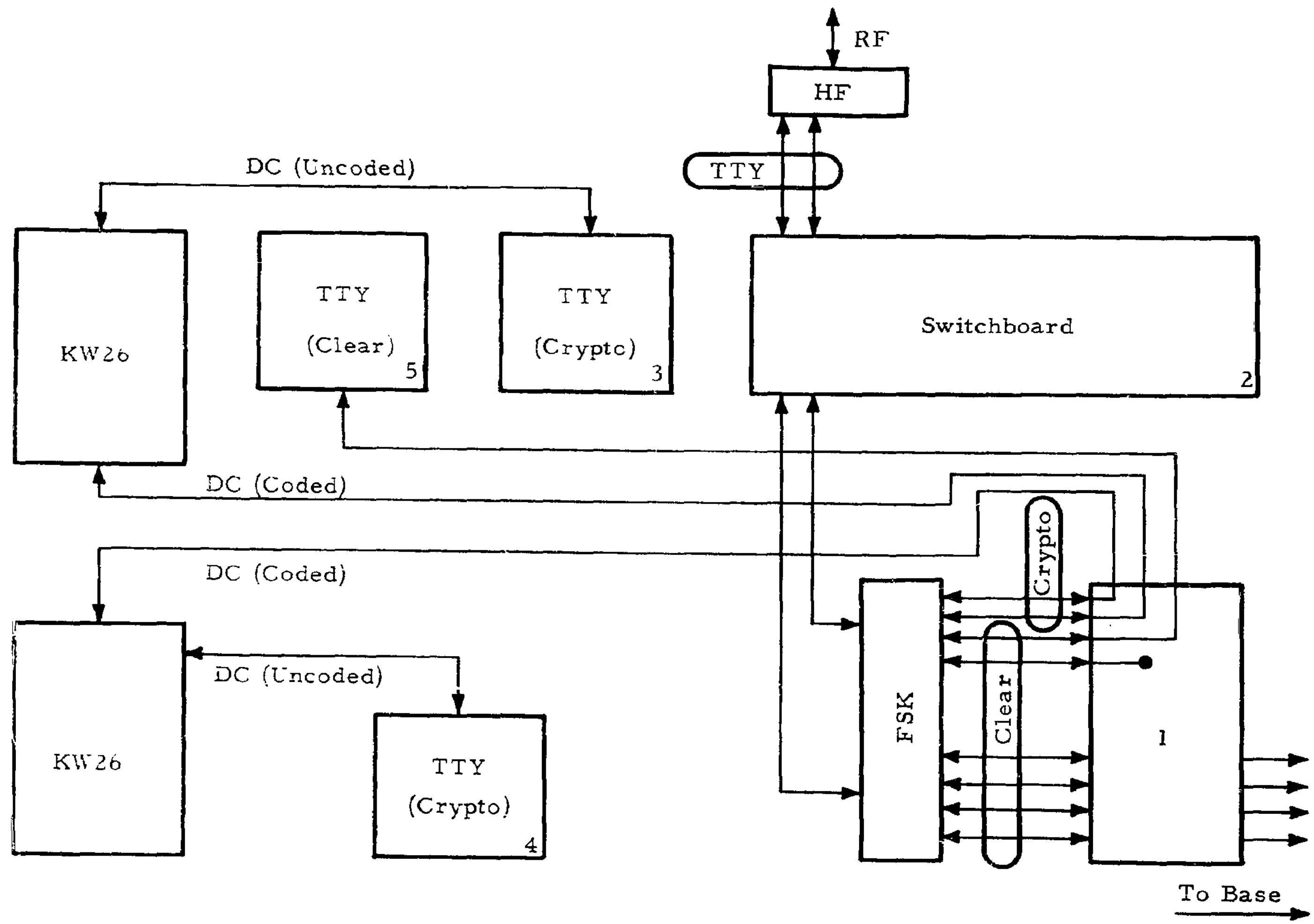


Fig. 5 - Teletype Communications Flow Diagram.

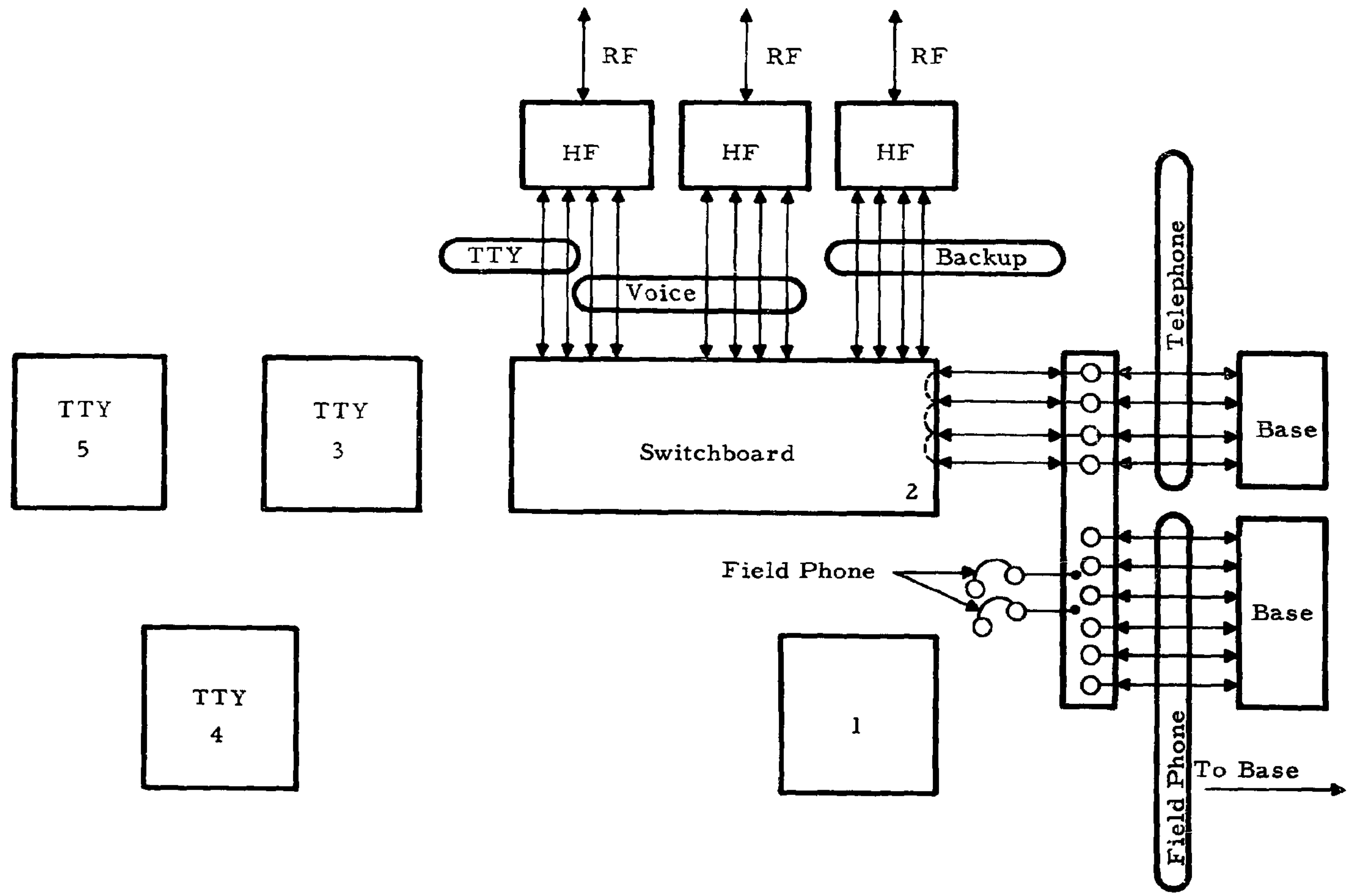


Fig. 6 - Voice Communications Flow Diagram.

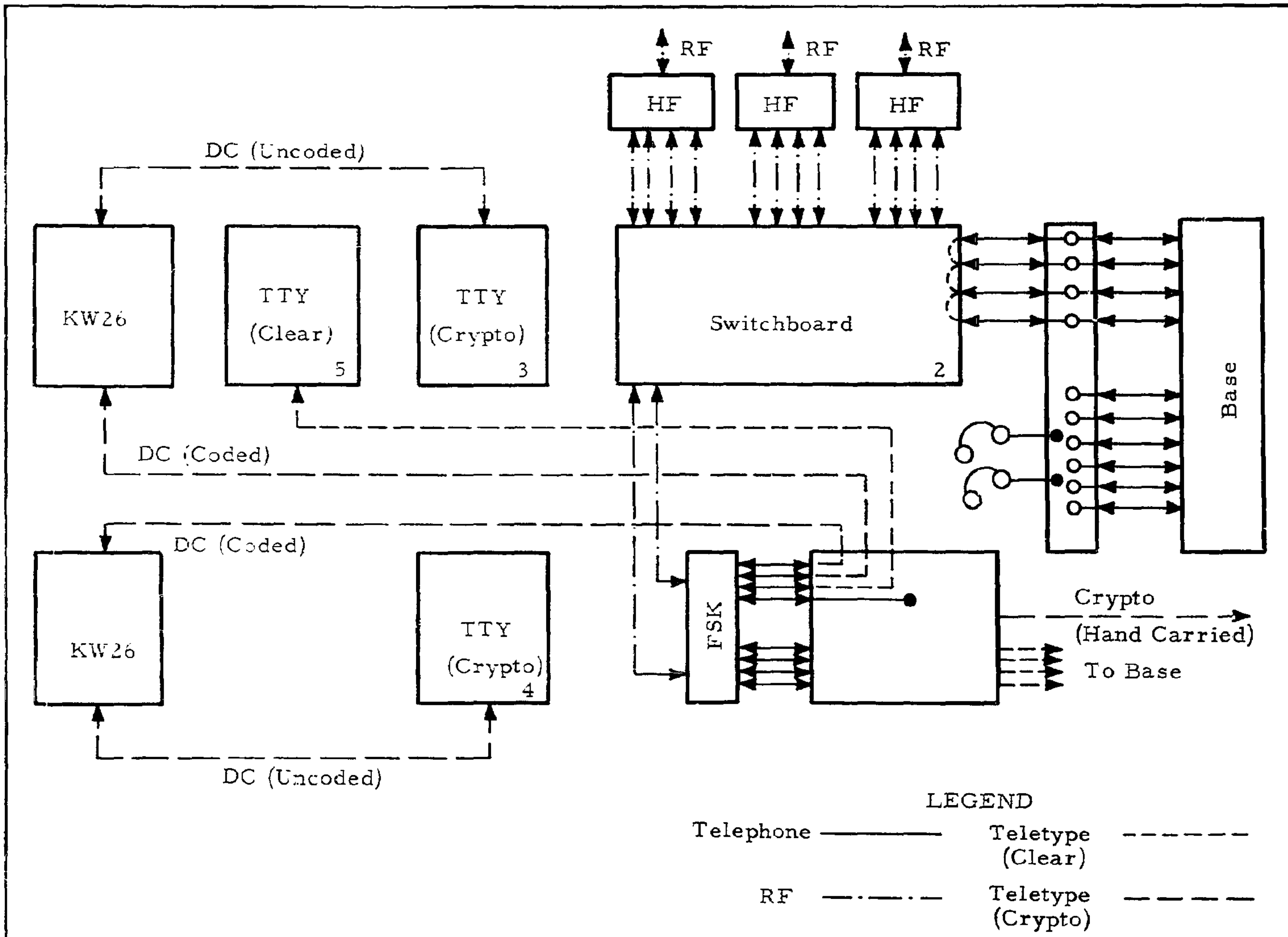


Fig. 7 - Composite Communications Flow Diagram.

2. Teletype Circuit Capability

There are three HF channels in the communications shelter. Each HF channel is divided into four different audio channels, providing a total of twelve audio channels. Since one HF channel (four audio channels) normally serves as backup, the operational capability consists of two HF channels (eight audio channels).

Two of these eight audio channels will be required to service the necessary teletype circuits. The other six operational audio channels are assigned to voice communication. In all probability, the two audio channels that are chosen for the teletype function will be split--one audio channel from each of the two operational HF channels. (It will be shown later that this is the optimum selection when diversification i. e., simultaneous transmission on two or more frequencies, is employed in an attempt to overcome poor transmission conditions).

Each of the two audio channels chosen for the teletype function contains four frequency tones. Each of these eight frequency tones is a possible teletype circuit and goes through FSK (Frequency Shift Keying) equipment that converts audio data to dc data. From here the eight teletypewriter channels are fed through jack fields into the teletype control panel located at operator position number 1.

a. Teletype Control Panel

The teletype control panel shown in Figure 8 is located at operator position number 1. It consists of eight columns of controls and indicators, one column for each teletype circuit; four diversity controls, one control for each pair of columns; teletype controls associated with the teletype machine located at this position, a dc loop current meter; and a two-wire or four-wire selector switch.

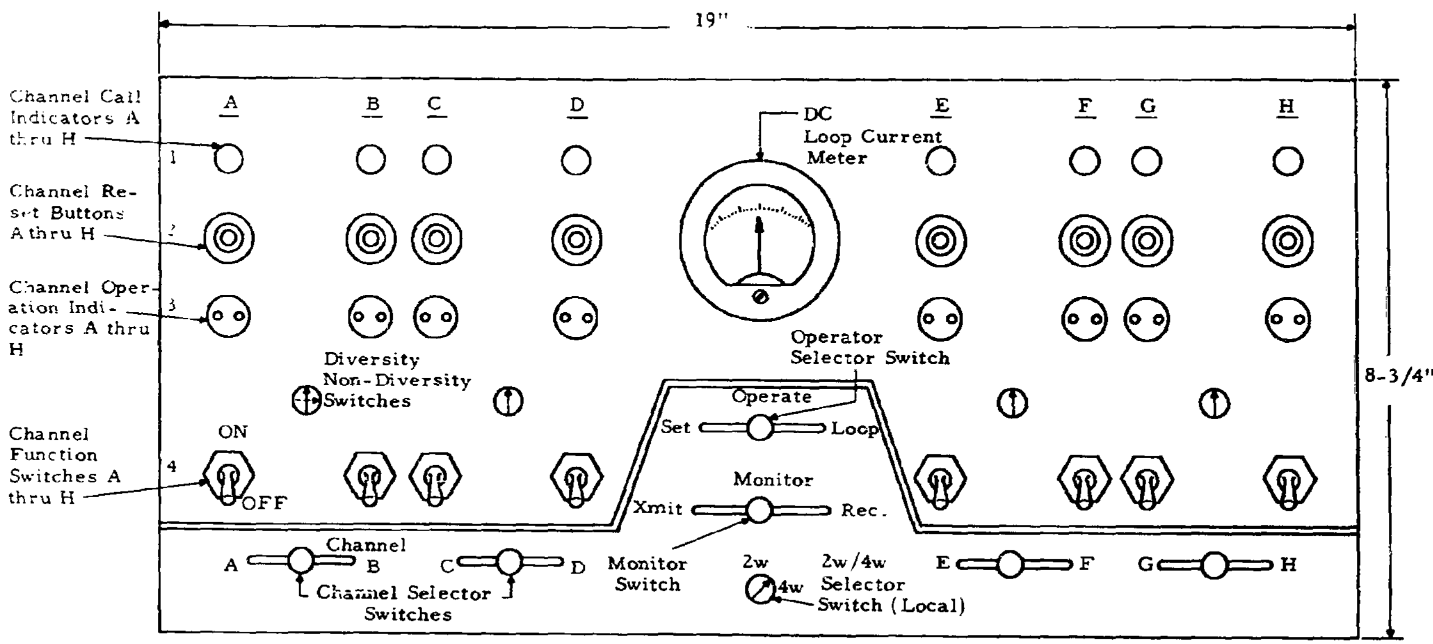


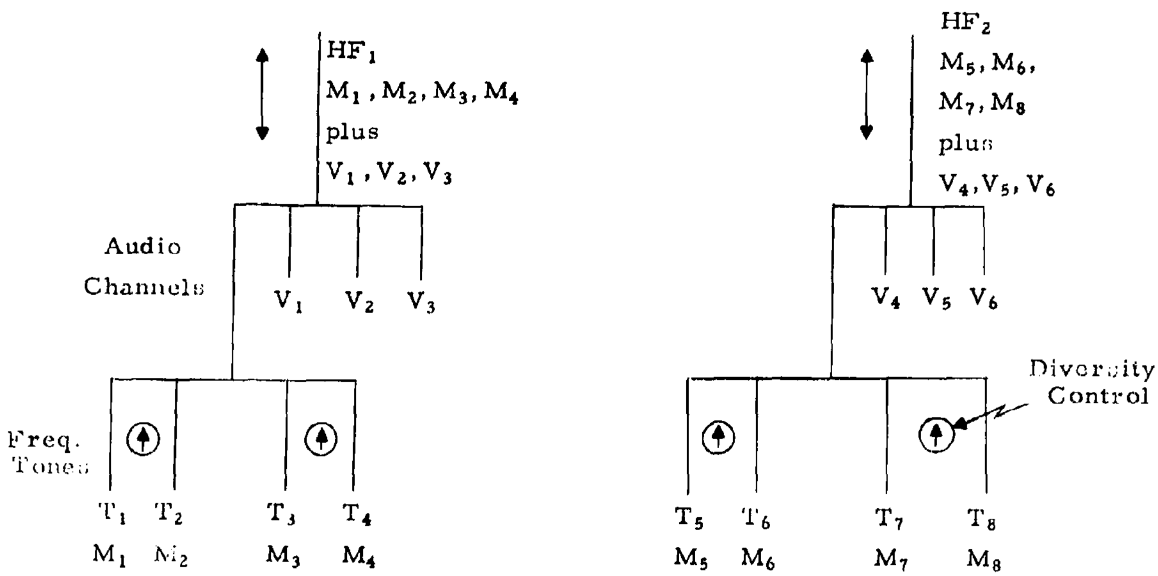
Fig. 8 - Teletypewriter Control Panel.

b. Assignment of Circuits to Control Columns

The assignment of each of the eight teletype circuits to one of the eight control columns (A through H) must be accomplished on the assumption that diversification will sometimes be necessary, depending on transmission conditions. When the transmission on a circuit (A) is diversified, the message is simultaneously transmitted on both circuits A and B, and thus is transmitted with greater power.

There are four diversity-nondiversity switches, located between control columns A-B, C-D, E-F, and G-H. This is a two-position on-off switch. The "on" position diversifies the high-priority transmission through both the left and right column frequencies. It should be noted that when a transmission on circuit A, for example, is diversified and transmitted on both A and B, the teletype transmission normally using B is "off the air" for as long as diversification is required. The communications system is thus capable of the following modes of operation.

(1) Eight nondiversified simultaneous transmissions/receptions. Schematically, this mode looks like this:

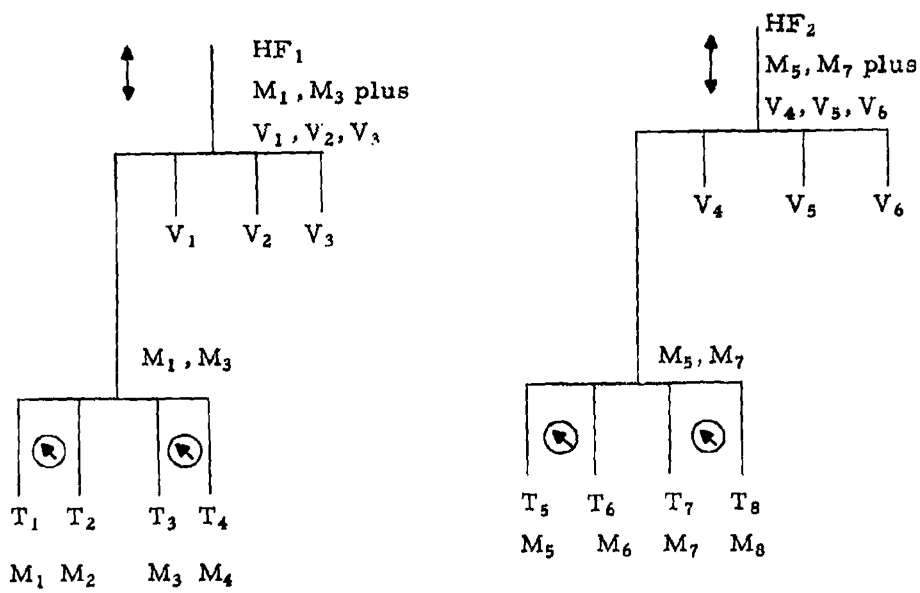


V = voice

T = teletype

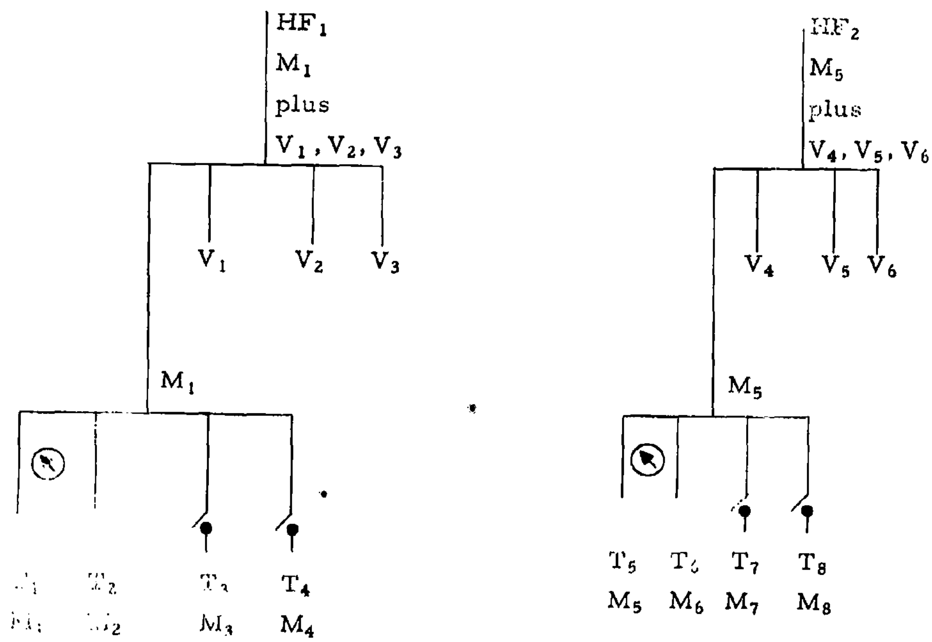
M = message

(2) **Four simultaneous diversified transmission/receptions. Schematically:**

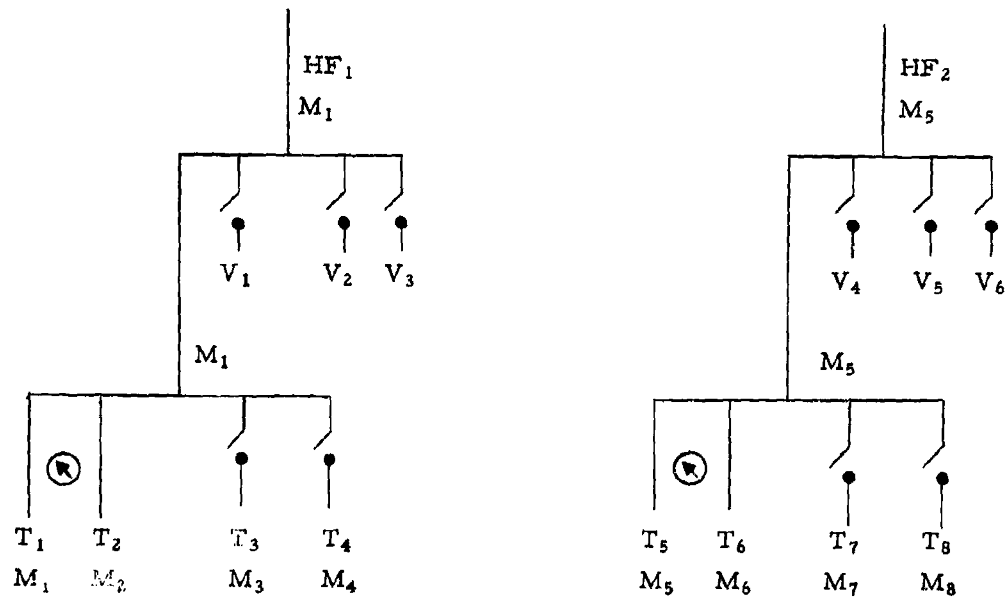


Since the teletype control is flexible, it is possible to achieve further power per transmission/reception. However, to achieve this, the switching must be accomplished between the teletype control panel and the switchboard. Some of these additional switching combinations (multiplexing) include:

(3) **Simultaneous transmission/reception of two separate messages, each message diversified, and each transmitted/ received through one of the twelve audio channels. Schematically:**



(4) **Simultaneous transmission/reception of two separate messages, each message diversified, and each transmitted/received through two of the twelve audio channels (when the other three audio channels for a given radio are shut down). Schematically, this mode would look like this:**



The preceding schematics describe the two extremes in terms of the simultaneous message capacity of the communications shelter. The one end point (maximum number of simultaneous transmissions/receptions) is the condition outlined as schematic number (1) above, while the other (minimum number of simultaneous transmissions/receptions) is diagrammed as schematic number (4). There are many points (control combinations) between these two extremes, as illustrated by schematics (2) and (3).

In general, the relationship is this: as transmission/reception conditions become less favorable, diversification is used to increase the probability of reception. The poorer these conditions become the more diversity and/or multiplexing is required and hence the fewer the number of simultaneous transmissions/receptions, that can be handled by the system. The net effect is a reduction in low-priority circuit capability under unfavorable transmission/reception conditions. (The latter is based on the assumption that as the total number of circuits is reduced through diversity and/or multiplexing, the remaining capability will be reserved for high-priority circuits.)

Considering the above information, the optimum assignment of circuit function to control column is that which maximizes the total number of high-priority transmission circuits under both extremes (when either little or much diversity is required). If we assume that both cryptographic circuits and the one unencrypted circuit are high-priority, we have a total of three high-priority circuits. Let us further assume that there will be a requirement for a high-priority "in-the-clear" circuit which is to be rerouted to a user command headquarters. We now have four high-priority circuits, each of which could be paired with four low-priority circuits. In this manner, circuit diversity can be provided as necessary without reduction in the high-priority transmission/reception capability.

Using this scheme, one crytographic circuit would be assigned control column A, while the other cryptographic circuit would be assigned control column E. (This would split the cryptographic function, one to each of the two operational HF channels, so that when transmission conditions become poor we could still have two simultaneous cryptographic transmissions).

The two high-priority "in-the-clear" circuits would be assigned control columns C and G. Control columns B, D, F, and H would be assigned to low-priority circuits.

c. Teletype Machine Configuration

Before describing the operations of the teletypewriters, it is necessary to present some background information on the manner in which they are coupled. Each teletype machine includes a keyboard, a punched tape distributor, a page printer, and a tape perforator/writer, and is capable of full duplex operation (i.e., each machine can send and receive simultaneously).

It was decided that both the home copy of outgoing crypto messages, and all incoming messages should be in the form of a page printed copy. In order to achieve this format for both home copy and receive copy, it is necessary to couple two teletypewriter machines with each KW-26 unit. Thus, four teletypewriter machines (coupled in pairs) are required to service two KW-26 cryptographic units. One teletypewriter machine per unit is receive only, and the other is send only. This configuration permits both reception and the production of home copy on page printers. Figure 9 outlines the teletypewriter capability in the communication shelter.

3. Operator Functions

The workspace arrangements and equipment in the communications shelter are set up for five operator positions. The following subsection will include a description of each operating position in terms of the equipment at that position, its capabilities, and the procedures involved in its use. The designation of operators is in accordance with Figure 1.

a. Position One - Supervisor

The operator at position 1 has control of the teletypewriter circuits and serves in a supervisory capacity as a message control, routing and dispatch center. Depending on the type of operation required, he may have to coordinate some specific control functions with the switchboard (e.g., during multiplex switching diversity modes three and four). He is also supplied with a teletypewriter equipped for clear text transmission only.

The controls and indicators incorporated in the Teletypewriter Control Panel permit the operator at position 1 to: (1) set up as many as eight simultaneous teletypewriter transmissions/receptions, (2) channel up to four simultaneous diversity transmissions/receptions, (3) monitor the transmit or receive side of any teletypewriter circuit, (4) transmit/receive on any eight teletypewriter circuits, (5) monitor the DC loop current, and (6) transmit/receive on local two- or four-wire circuits.

Assuming that there is a requirement for eight teletypewriter circuits, and further assuming that each circuit is assigned a control column on the basis of the rationale previously outlined, the operator at position 1

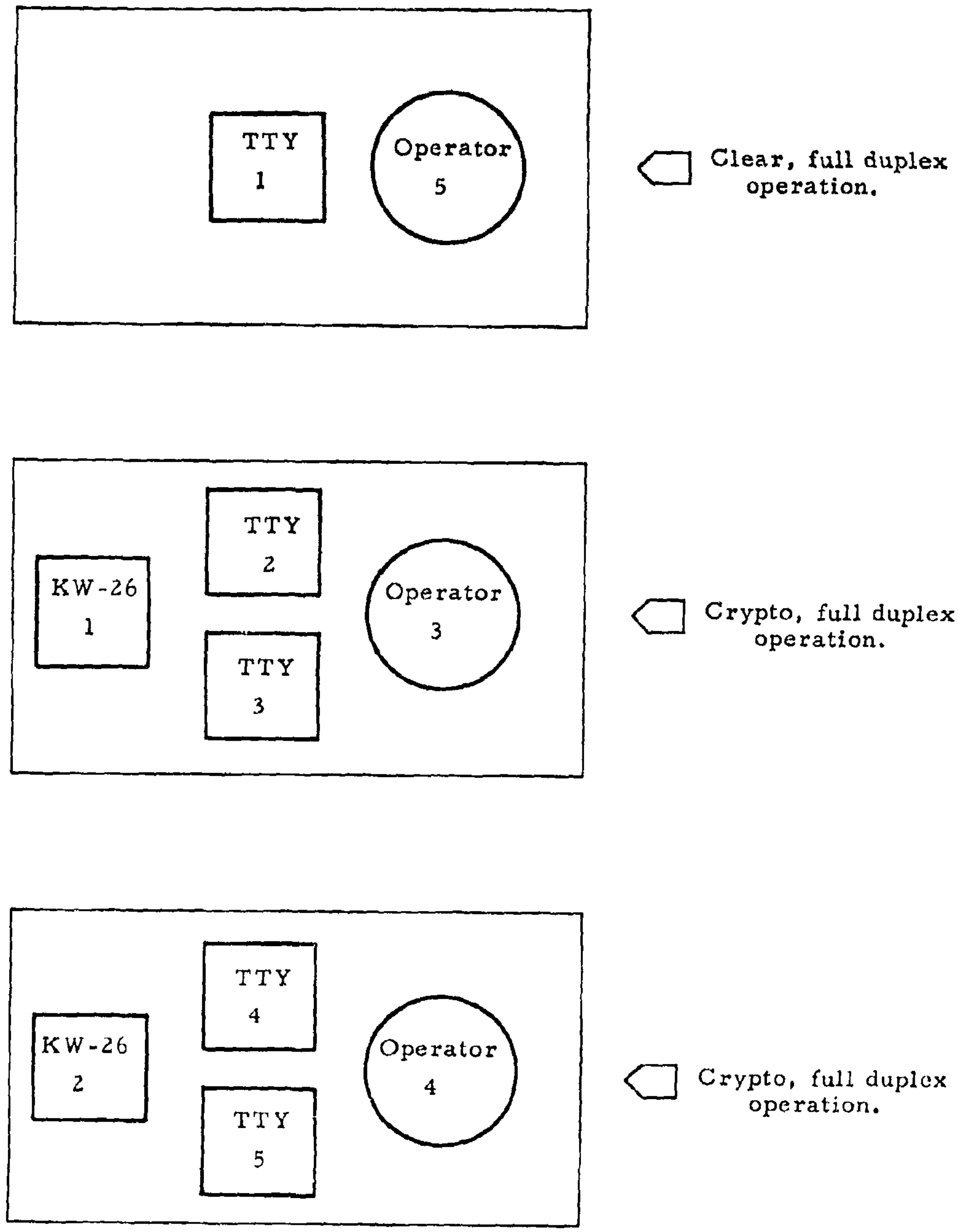


Fig. 9 - Teletypewriter Capability

performs these functions as follows:

To permit up to eight simultaneous teletypewriter transmissions/receptions, the operator places the Channel Selector Switches (4, A-H, Figure 8) up to the ON position. This places the eight teletypewriter circuits on the prescribed audio channels for transmission/reception through the radio channels.

To permit up to four simultaneous diversity transmissions/receptions, the operator at position 1 would move all four of the DIVERSITY-NONDIVERSITY controls to the ON DIVERSITY position.

To monitor the transmit or receive side of any teletypewriter circuit, the operator at position 1 moves the appropriate Channel Selector Switch to the channel position he desires to monitor, and selects either the Transmit or Receive position (whichever is desired) on the Monitor Switch. The material that is being transmitted or received on the monitored machine will be duplicated on the position 1 machine.

To transmit/receive on any eight teletypewriter circuits, the operator at position 1 places the appropriate Channel Selector Switch to the desired channel and places the Operator Selector Switch to LOOP (for local transmission/reception) or SET (for radio transmission/reception). In the latter case, the operator must also move the appropriate Channel Function Switch (4, A-H, Figure 8) to the ON position.

b. Position Two - Switchboard Operator

The primary duty of the operator at position number 2 is to maintain voice communications between AIRCOM, and the user commands of AN/TSQ-47. To a limited extent, he is also responsible for maintaining communications between the user commands over telephone lines, when these are available.

Since all inputs to the communication center come through the switchboard, the operator at this position must initially set up the two audio channels that are to service the teletype control panel at operator position 1; which is accomplished by means of normalized jacks if the connection is to be relatively permanent. From this point on, the switchboard operator's duties in regard to the teletype circuits are limited to changing the teletype audio channels or setting up multicoupling when required.

The cordless switchboard is the control link between the audio channels and the telephone circuits. Since there is provision for routing only four of the ten telephone circuits through the switchboard at any given time, and since two of the twelve audio channels are required for the teletypewriters and four audio channels are back-up, the control link at the switchboard is normally between six audio channels and four telephone circuits. This means that there are four independent patches, each capable of connecting two circuits together (telephone to telephone, telephone to radio, radio to radio). Two separate pairs of connecting circuits may be joined together for a four-way conference. Both operators may also join in as the fifth and sixth parties.

The six telephone circuits that are not routed through the switchboard may be connected to either of two field phones that are provided.

In addition to patching the six audio channels to the four telephone lines, the operator controls the radio transmitter frequency and RF gain, simplex/duplex operation, high/low power, keyline, and AM-SSB-CW operation.

In general, the operator at position 2 in the communication shelter can call, answer, and control all switchboard circuits -- four telephone, six operational audio, and four audio back-up. Some incoming messages, either by intent or due to busy telephone lines, will be terminated in the center (either permanently or temporarily). Messages of this nature must be recorded on the typewriter provided, and will subsequently either be used in the center or sent out on a telephone line when one becomes available. The time-consuming nature of this duty may, on occasion, require this position to be a two-man operation. At such times, the regular operation would be supplemented by one of the other regular operators assigned to the shelter, or by a sixth operator.

c. Position 3 and 4 - Teletypewriter Operators #1 and #2

Since the equipment of the two cryptographic teletypewriter operators is identical, their operations will be considered together. However, one of these two operators must also perform minor maintenance on the KW-26 units. This will involve changing code cards when required, and synchronizing the KW-26 units when operation is resumed after any power shut-down.

While the receive operation for cryptographic material is rather automated, the send portion of the operation is manual. The requirement that the home copy of all outgoing cryptographic messages be page-printed, and the characteristics of the transmitting equipment, both indicate the following sequence of operations.

After the operator has been given the message for transmission, he will punch a tape of the message using the keyboard. This tape contains the desired characters in both perforated and type form. The typed character appears on the tape just below the perforation. The perforating and typing occur at the extreme right side of the machine, and as the tape passes from right to left, approximately one full line of material is exposed. This will provide the operator with positive feedback regarding any errors that might have occurred. If the operator notices an error, he notches the bottom edge of the tape at the location of the error. He continues in this fashion until the message is completed in tape form. This first tape will be called the "error tape" to avoid confusion later in the discussion.

The next step is to place the "error tape" in the distributor which automatically duplicates, in either tape of page-printed form (or both), any tape it contains (in this case the "error tape"). Wherever the "error tape" has an error notch, the distributor stops, permitting the operator to correct the error on the new tape. After this operation is completed, he has both an "error tape" and a "corrected tape," and the "error tape" can be destroyed.

The next and final operation is to place the "corrected tape" in the distributor for automatic transmission. As the "corrected tape" is being transmitted by the distributor, a page-printed home copy is simultaneously produced as a record. After the message has been completely transmitted, the "corrected tape" may be destroyed, and the page-printed home copy may be filed.

In reviewing the steps in this operation, it is apparent that a large percentage of the operator's time is involved in PREPARING the message for transmission, rather than in actually transmitting the message. However, once an error has occurred, it is impossible to correct on the same tape, since it would be mutilated by the excess perforations. If field conditions should prove that this operator's time is critical, it would be worthwhile investigating the error rate of experienced operators and the information that is actually lost as a result of these errors. It may be hypothesized that redundancy factors would largely overcome the information loss resulting from errors, and that operator times requirements could be reduced (by eliminating the need for preparation of "corrected tapes") without reducing the system effectiveness.

d. Position 5 - Teletypewriter Operator #3

With the exception of a few minor differences, the equipment at this position is operated in the same fashion as the cryptographic teletype machines. The unencrypted over-all teletype machine configuration uses only one machine while maintaining a full duplex capability. The reason for this is that the reception is on the page-printed portion of the machine, while the home copy is in the form of a tape generated by the perforator-type portion of the same machine. Other than this difference, the operational steps are the same. To repeat: the operator generates an "error tape" complete with error notches, runs this "error tape" through the distributor to generate a "corrected tape," and places the corrected tape in the distributor for transmission. The "corrected tape" is retained as the home copy, and reception is in the form of a page-printed copy.

The teletype machine at position 5, as well as the machine at position 1, is for transmitting and receiving "in-the-clear" messages only. The pairs of machines assigned to the two KW-26 units are for transmitting and receiving cryptographic messages ONLY, The frequency and duration of traffic rates for either type of message have not yet been determined, and therefore no estimate of the relative loads on teletype operators can be made at this time.

C. AIR TRAFFIC CONTROL CENTER, AN/TSW-5(IFR)

1. Shelter Layout

The principal consideration in the design and layout of both fixed and mobile IFR facilities should be the flow of aircraft control information through the various functional positions within the shelter. Because of the nature and quantity of this information, it must flow through the various control stages as rapidly, smoothly, and efficiently as possible from the time each aircraft initially enters the control area until the landing has been completed; or in the case of departure, until the aircraft is clear of all area traffic.

The hand-off of aircraft control from one controller to another involves spoken as well as written communications. When controllers positions are not properly located with respect to the sequential flow of control information, voice communication efficiency is reduced. This, in turn, may result in loss of information, errors, channel congestion due to repetition of messages, and a general increase in the total noise level of the facility. These problems can be eliminated, or greatly reduced, by positioning the controllers and their respective displays in such a way that control hand-offs always occur between adjacent controllers.

In fixed IFR facilities the equipment layout normally emphasizes an in-line configuration. This type of layout provides a direct line flow of control information, since normal hand-offs occur between adjacent controllers, but it does require an extensive amount of floor space. The attainment of efficient information flow is more difficult in a mobile system, since size and weight constraints limit the configurations which can be employed, and consequently reduces the feasibility of in-line operations. In addition, operator work areas, normally adequate in fixed, in-line facilities, becomes a very definite problem in the layout of a comparatively small mobile shelter. Thus, the task of achieving an adequate man-machine equipment layout in a mobile IRF facility, requires an arrangement of equipment that will provide the necessary operator work area and at the same time ensure a smooth, efficient flow of communications.

The number and type of equipments, and the number of personnel required to operate the AN/TSQ-47 IFR facility, precluded the use of the standard 12-foot shelter. This problem was resolved by specifying the use of a mobile shelter with telescoping sides for the main facility, and a 76-inch annex shelter to house all the air-ground-air communications equipment. Figure 10 illustrates the floor plan of the expandable shelter in the "operation" state, and Figure 11 "in-transit" with the sides of the shelter telescoped into the main section to facilitate mobility.

This layout offers the best solution to accommodate equipment and operating personnel within the available space. However, some minor compromises are necessary during operation. One such compromise between operator work area and optimal equipment positioning can be seen in Figure 10. To ensure and maintain a sequential flow of control information, operators #1 and #9 must be seated in door entry areas. This presents no problem in the case of operator #9, since the 36-inch entrance will be used only for the removal or replacement of large equipment. Operator #1, however, may be required to shift his chair position slightly whenever the personnel entrance is used during operation. Such occurrences should be few, and hence should not present a serious inconvenience.

Figures 12 and 13 illustrate the overhead positioning of the intershelter communications units and indicator power supplies, and the general workspace layouts of the individual controller consoles. Overhead positioning was used whenever possible to conserve operator workspace without jeopardizing accessibility to units for control manipulation and maintenance.

Figure 14 illustrates the horizontal indicator and the optical overlay projector unit positioned above it. Also, it shows the general workspace layout for the four controllers positioned around the horizontal PPI. The horizontal surveillance display is designed for sit-down operation, with the indicator face 33 inches above the floor. Since the sitting height of 90% of the AF population ranges from 33 to 38 inches (top of seat to top of head), the stools provided for these controllers should be adjustable over a height ranging from 22 to 27 inches This would provide almost all controllers with a comfortable working height and permit easy access to the communications selector panel located in the overhead unit.

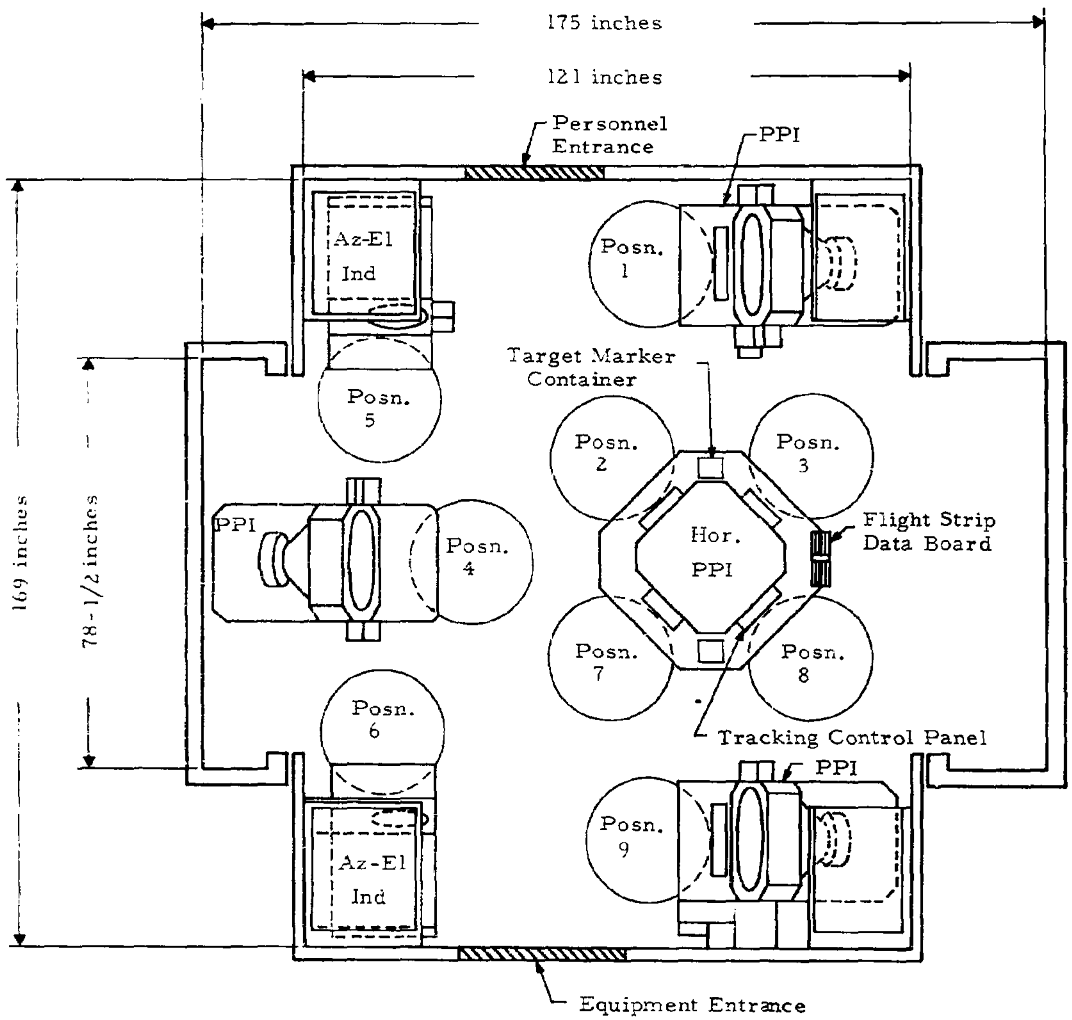


Fig. 10- IFR Shelter Floor Plan (Operational).

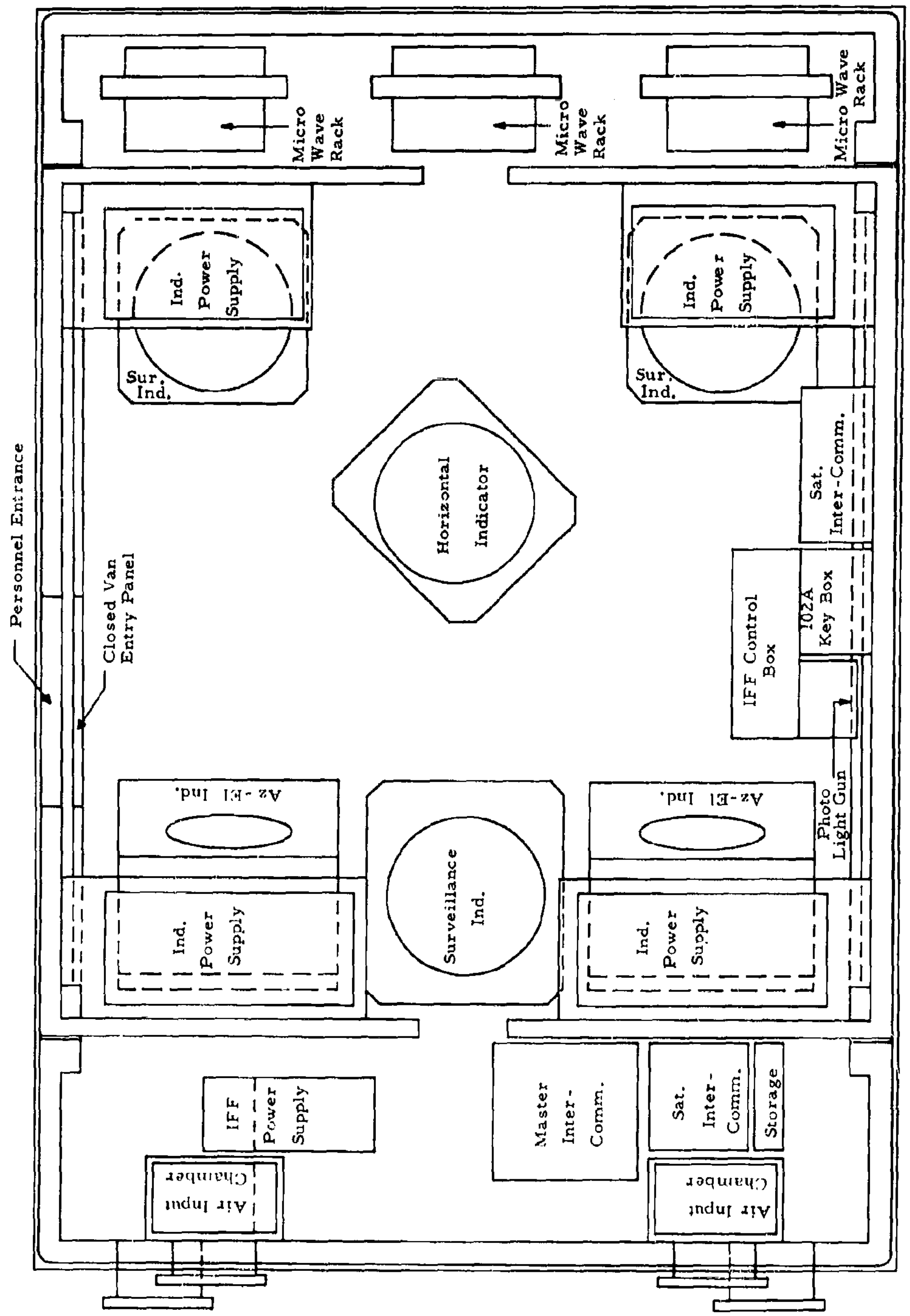


Fig. 11 - IFR Shelter Floor Plan (In-Transit).

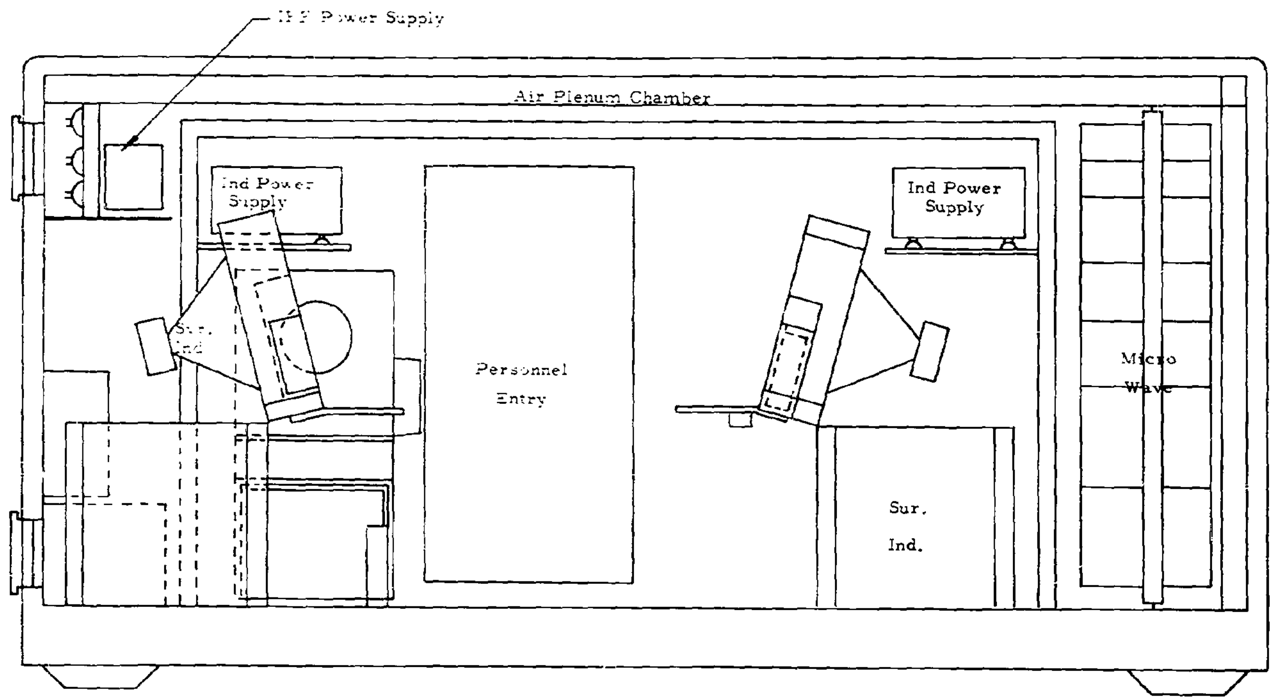


Fig. 12- IFR Shelter Side View (Operational)

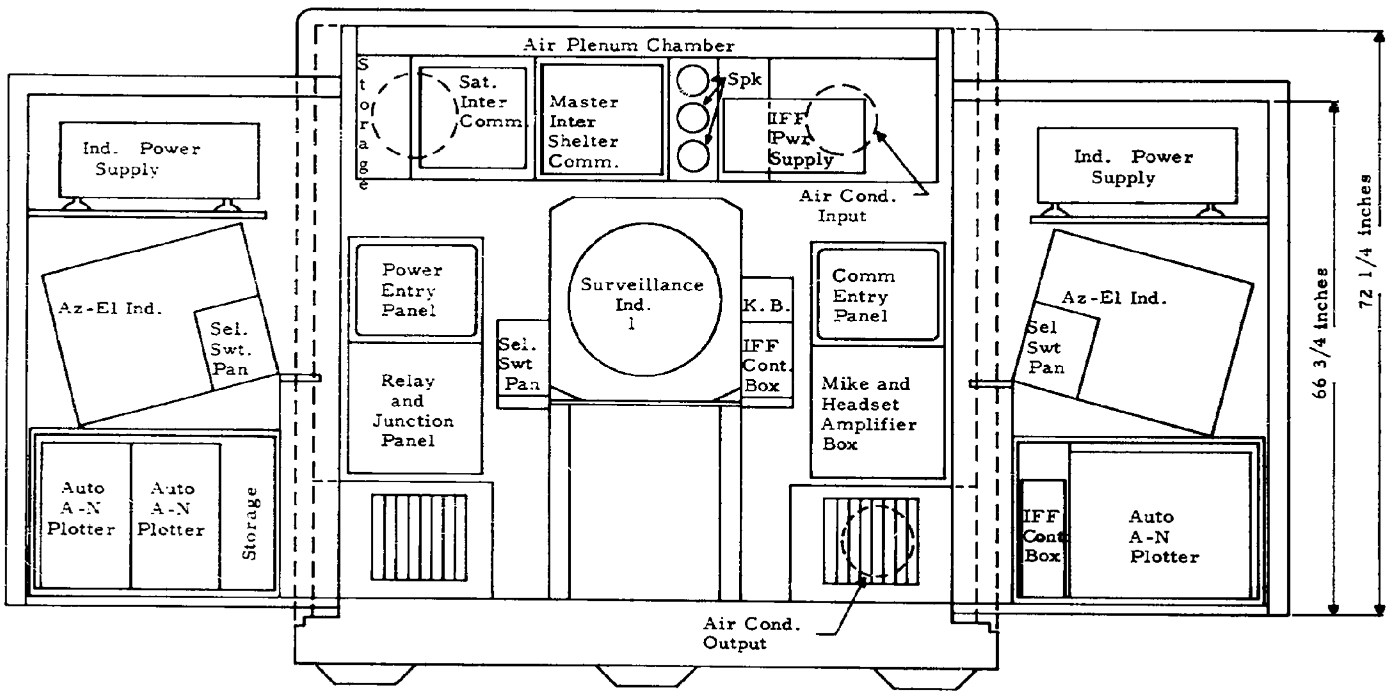


Fig. 13 - IFR Shelter End View (Operational)

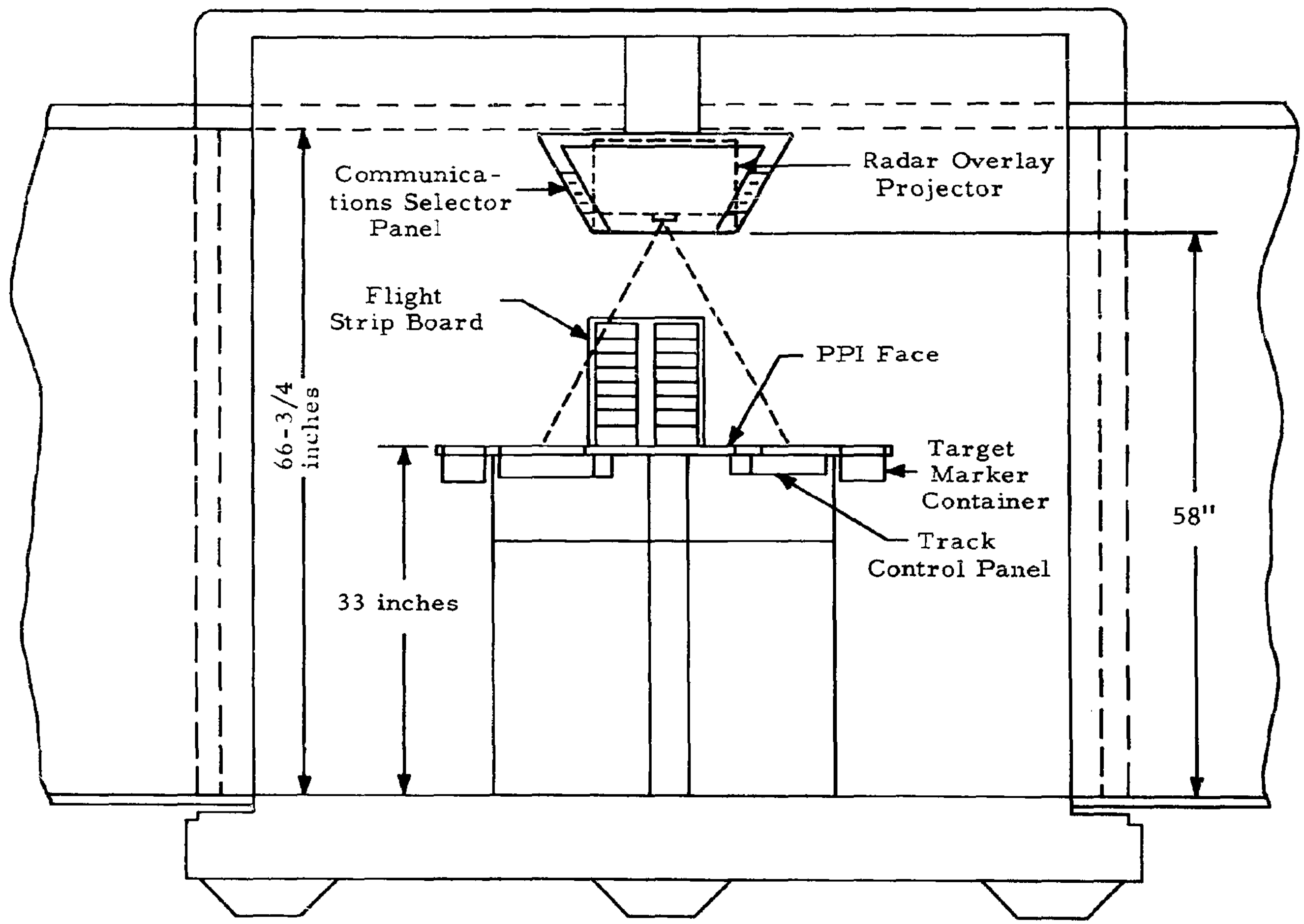


Fig. 14 - Horizontal Indicator and Overlay Projector.

The location and design of the overhead unit present a few human engineering problems. This unit, which contains a communications selector panel for each of the four controllers grouped around the horizontal indicator and the projection unit (consisting of two optical projectors and one ultraviolet projector), must be centered above the indicator to permit undistorted projection and access to controls from all positions. The major problem associated with this structure involves its potential interference with movement or visibility around the indicator.

The over-all height of 95% of the Air Force population during sit/stand operation will range from 55 inches (short men sitting on stools in the low position) to 75 inches (tall men standing). The taller men will present the greatest problem due to the restriction in overhead clearance. Since the interior height of the center section of the shelter is only 72-1/4 inches, taller men will have to stoop whenever they stand. This problem will not exist in the sitting position since the upper height limit will be approximately 60 inches (with stools in the low position).

The overhead unit, however, does present problems in terms of both physical and visual clearance. Several considerations serve to limit the design flexibility of this structure. These are shown in Figure 14 and include: (1) the requirement that the unit remain in place during transport; (2) the ceiling height of the expandable portion of the shelter (which retracts into the center of the main shelter during transit, leaving only a 6-inch space between its two sides); and (3) the depth of the unit itself, which must be sufficient to accommodate the selector panels and the optical equipment.

The overhead configuration shown in Figure 14 is the best compromise solution. The top of the main structure cannot be higher than 66 inches because of the retracting ceiling, and since the unit must be at least 8 inches deep to accommodate its component hardware, the bottom of the unit cannot be more than 58 inches from the floor.

A structure at this height would constitute a physical hazard to almost all controllers in the standing position, and also to the tallest controllers in the sitting position. The inverted-cone shape of the unit is designed to minimize this hazard by placing the lowest portion of the structure over the center of the indicator. The configuration also minimizes the visual interference caused by the structure. The upper limits of eye height for Air Force personnel will range from 56 inches (sitting) to 70 inches (standing). Thus the suggested structure will provide clear visibility for all seated controllers and will minimize the interference in the standing position. The sloping sides will also provide ready access (visual and physical) to the selector panels since these will be perpendicular to the plane of view of a controller as he looks and reaches upward to make a channel selection.

2. Communication Capabilities

Air-ground-air communications capability in the AN/TSW-5 mobile IFR shelter includes one HF, six VHF, and seven UHF transceivers; providing a total simultaneous broadcast capability of fourteen air-ground-air (A-G-A) audio channels. In addition to these UHF/VHF/HF facilities, intershelter and land-line telephone communications capabilities are provided by two master and one satellite intershelter-communications transceivers, and three land-line telephone keyboxes. The bulk of the communications equipment is housed in the IFR Annex shelter as shown in Figures 15, 16, and 17.

The antenna configuration necessary to accommodate the sixteen transceivers is illustrated in Figure 18. To conserve on weight, maintenance, mounting operations, and storage area, the thirteen UHF/VHF transceivers are coupled, through UHF and VHF multicouplers and filters, to two UHF two-bay-array antennas and two VHF broadband dipole antennas. These four UHF-VHF antennas are in turn combined, in an alternating pattern, as a colinear stack with one UHF two-bay-array antenna at the top. The single HF transceiver is coupled to a broadband HF whip antenna, and each of the master intershelter-communications transceivers is coupled to a VHF whip antenna.

a. Intershelter Communications

The intershelter-communication system plays a key role in effective total system performance. It is primarily used to exchange information and coordinate landing clearances with the VFR tower, and for traffic coordination with other agencies. In addition, it will be used to link controllers in the IFR shelter with maintenance personnel in the ASR and PAR radar shelters

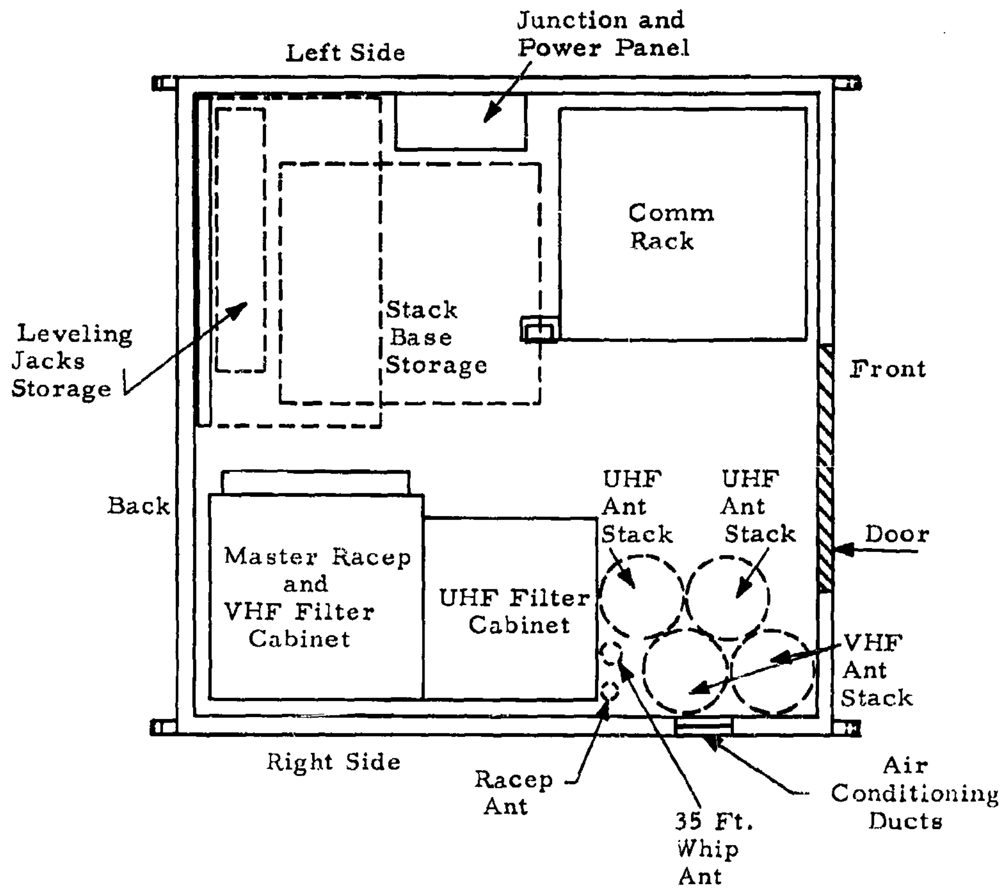


Fig. 15 - A-G-A Shelter (IFR Annex), Floor Plan

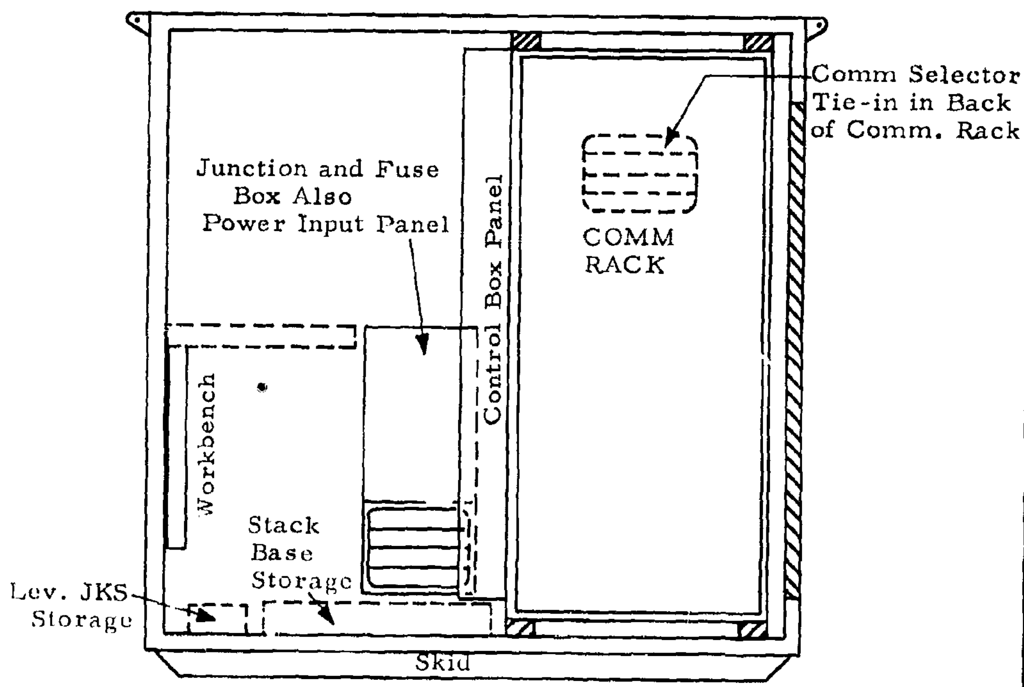


Fig. 16 - A/G/A Shelter, Left Side

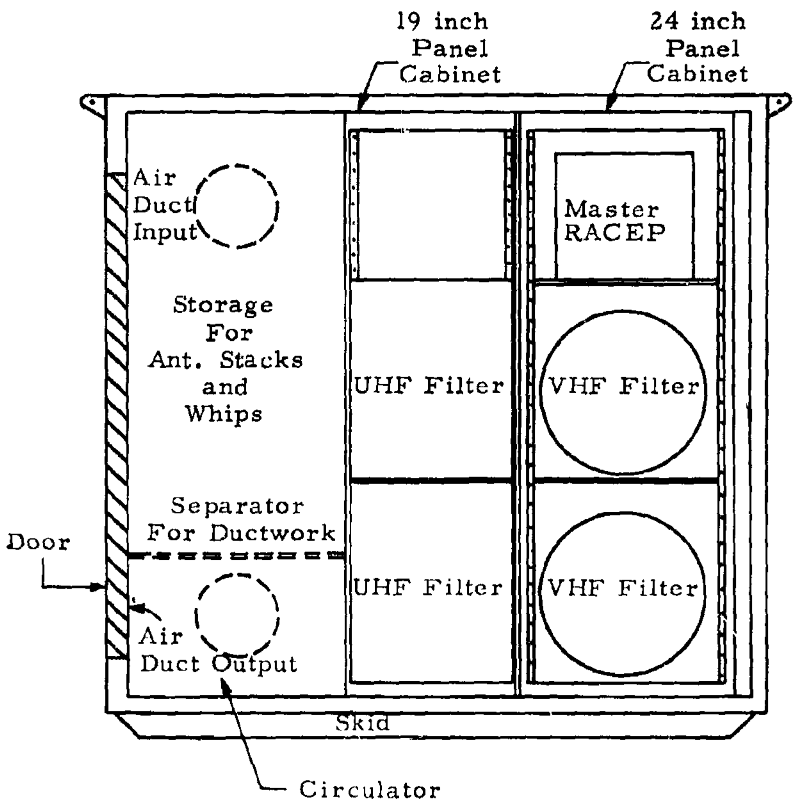


Fig. 17 - A/G/A Shelter, Right Side

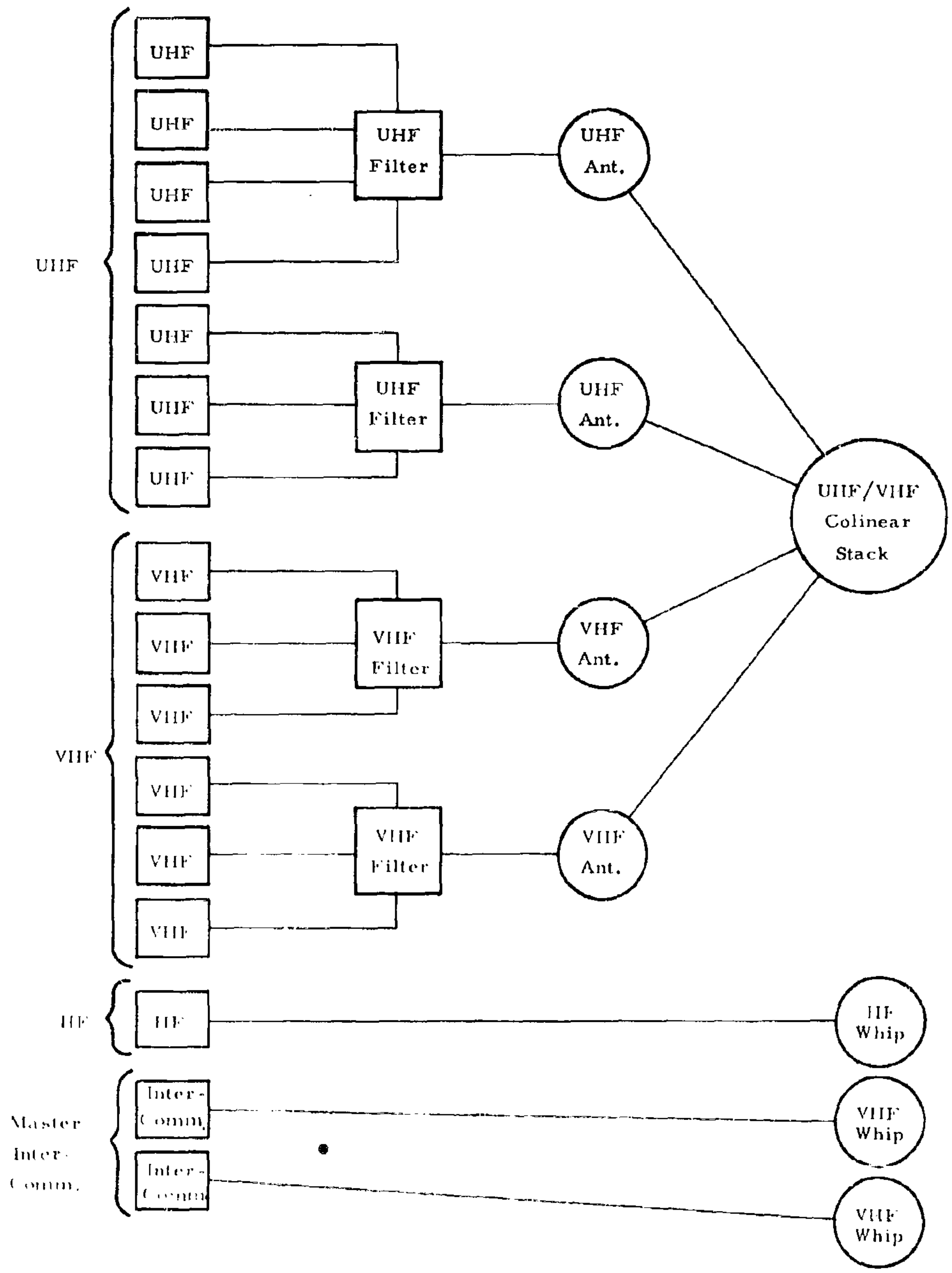


Fig. 18 - Antenna Configuration.

during initial radar and indicator alignment and for subsequent readjustments. All ECCM operations between the IFR and ASR shelters will also be controlled through the intershelter-communication system. Further descriptions of radar alignment and ECCM operational procedures will be presented in subsection F covering the ASR shelter.

b. A-G-A Communications

The prime function of the IFR shelter is control and coordination, both of which rely heavily upon the efficient flow of communications. Therefore, it will be necessary to insure complete coordination of communications equipment, channel allocations and procedures. This is especially important for a mobile system since the large volume of voice communications traffic, all of which requires integrated action and sequential transfer from position to position, must be handled with a limited number of channels.

In view of these complicating factors, the communications control assignments set forth in Figure 19 seem to offer the most acceptable and flexible solution. This configuration provides:

(1) Individual headset/microphones and channel selector boxes for each controller station.

(2) One UHF, VHF, and HF channel common to all positions for use as a guard or emergency frequency.

(3) A distinct primary channel, in both UHF and VHF, for each functional station.

(4) A capability to use any of the 14 channels from any station.

(5) Multiple land-lines, intershelter communications, and speaker locations within the shelter.

In spite of the limited number of available channels, it is still possible to provide each functional station with a prime, a secondary, and a guard channel for both UHF and VHF. This, of course, means that some sharing of frequencies must occur, but in all cases the allocations have been made so as to prevent duplication of prime channels assignments, at least between stations

Operators	Operator Designation	UHF (Audio)	VHF (Audio)	HF (Audio)	Inter-Shelter Comm.	Land Lines	IFF
Operator No. 1	Pickup Controller	Channels 1, 2, 7	Channel 1, 2, 6	Channel 1	Channel 2	No. 1	Channel A
Operator No. 2	Approach Controller	Channels 2, 1, 7	Channels 2, 1, 6	Channel 1	Channel 2	No. 1	-----
Operator No. 3	Approach Controller Assistant	Channels 2, 1, 7	Channels 2, 1, 6	Channel 1	Channel 2	No. 1	-----
Operator No. 4	Feeder (Turn-on) Controller	Channels 3, 6, 7	Channels 3, 6, 6	Channel 1	Channel 3	No. 2	Channel C
Operator No. 5	Final Approach Controller No. 1	Channels 4, 5, 7	Channels 4, 5, 6	Channel 1	Channel 3	No. 2	-----
Operator No. 6	Final Approach Controller No. 2	Channels 5, 4, 7	Channels 5, 4, 6	Channel 1	Channel 3	No. 2	-----
Operator No. 7	Departure Controller	Channels 6, 3, 7	Channels 6, 3, 6	Channel 1	Channel 2	No. 3	-----
Operator No. 8	Departure Controller Assistant	Channels 6, 3, 7	Channels 6, 3, 6	Channel 1	Channel 2	No. 3	-----
Operator No. 9	Supervisor Coordinator	Channels 1, 2, 7	Channels 1, 2, 6	Channel 1	Channel 1 (master)	No. 3	Channel B

NOTE: The term "channel" as used in this report refers to equipment units rather than to specific frequencies.

Fig. 19 - Communications Assignments.

(considering a controller and his assistant to be a single station). This is a very necessary prerequisite to the smooth coordination of traffic flow and hand-offs since it eliminates the need for continual frequency shifting by controllers and also reduces the probability of a pilot using a given frequency to contact a specific position (e.g., the Pickup Controller) only to find himself talking to a different position.

3. Number and Functions of Operators

The workspace arrangements and equipment in the IFR Shelter are set up to accommodate nine operators. The following subsection will include a description of each operating position in terms of equipment at that position, its function, and the duties of the operator at that position. Figure 10 illustrates the equipment layout and the operating positions.

a. Position One - Pickup Controller

Functions: The Pickup Controller is responsible for the initial radar contact, identification and scheduling of all aircraft entering the perimeter of the control area (the actual size of this area will be determined by the system mission, terrain, etc., but the display will have a range capability of up to 275 nautical miles). The specific duties of this operator include:

(1) Detecting and establishing radar identification for aircraft entering the control area or zone.

(2) Transmitting headings, position reports, weather, field information and subsequent radio frequency assignments to pilots.

(3) Advising pilots and/or other controllers of any hazards.

(4) Establishing general conditions concerning the aircraft (e.g., fuel status, damage, altitude, etc.).

(5) Communicating with the Approach Controller (or assistant) to coordinate transfer of control and to keep that station current on anticipated traffic loads.

(6) Assigning symbols and tracks to arriving aircraft.

The pickup controller station will be on the left side of the IFR shelter and will consist of the following major elements: a console-mounted 22-inch Plan Position Indicator (PPI) with its associated controls (including IFF/SIF); a pickup panel and light gun for use in acquisition and track/symbol positioning of the automatic tracking and symbol generating group; and communications selection and control facilities.

The Controller will use these equipments to detect, identify, track, and communicate with aircraft entering the control area. The Controller must survey the perimeter of the assigned control area and detect the arrival of incoming or overflying aircraft as they enter this zone. His next steps are to establish communication with the aircraft to determine its identity and provide it with instructions, and to establish radar identification. The Controller selects the appropriate UHF or VHF channel for communication by means of switches on his communications control box. He may use such features as MTI and IFF/SIF to aid him in establishing radar identification.

Once communications and identity have been established, and the aircraft is within an 80-mile range, the Pickup Controller may insert the aircraft into the symbol-tracking group to provide automatic tracking and an alphanumeric symbol for that aircraft. The decision as to whether the aircraft will be inserted into the automatic tracker will be based upon the over-all traffic loads, the availability of tracking channels, etc.

At this point he will usually hand the aircraft off to the approach control station and inform the pilot of this fact, and the new frequency channel to which he should shift. Any unusual conditions or coordinations may require the Controller to communicate with other aircraft (using the communications selector box), other controllers (using the intershelter communications) or other base facilities (using the land-line telephone). All of these equipments are available at his console.

Communications: Figure 20 illustrates the communications switch panel used for channel selection at this position. The three UHF, three VHF, one HF, and one intershelter-communications switches on each panel represent the eight audio channels assigned to each operator.

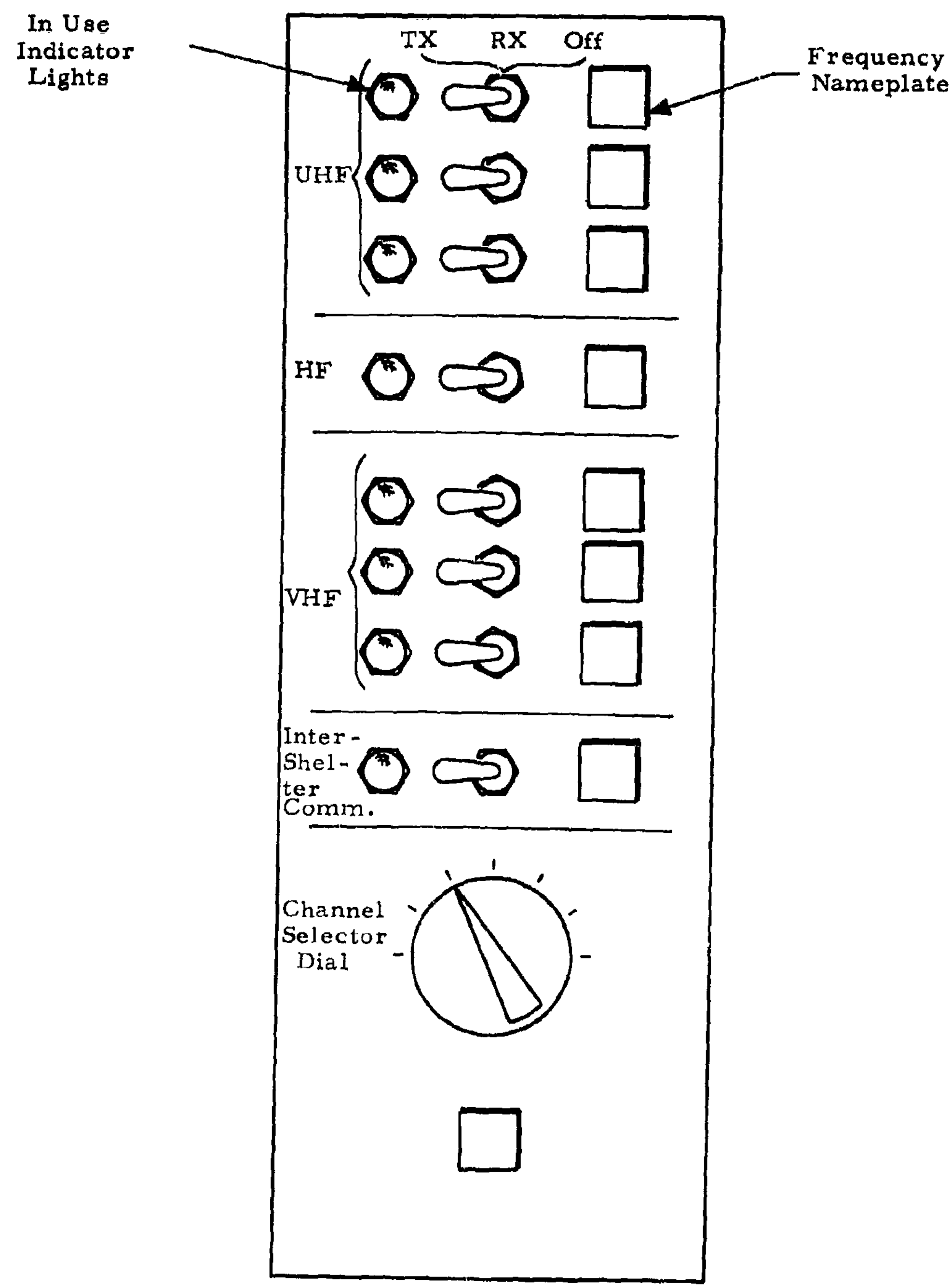


Fig. 20 - Communications Channel Selector Panel (Operators 1, 4, 5, 6, and 9).

In addition to his six assigned UHF/VHF channels, each operator may transmit/receive over any of the seven UHF/VHF channels not specifically assigned to his position. This is accomplished by means of the channel selector dial on each panel. The dial is essentially a nine-position rotary switch with an OFF position, and seven transmit/receive positions. These represent the remaining seven channels not available by the six UHF/VHF switches at any specific position. The ninth position on the dial is a spare switch. Tuning the dial switch to a particular channel performs essentially the same function as throwing the switch of an assigned channel to the transmit/receive position. The channel selector panel thus provides each operator with full transmit/receive capability over any of the thirteen UHF/VHF audio channels, should the need arise.

As shown in Figure 19 the Pickup Controller has been assigned UHF channels 1, 2, and 7, VHF channels 1, 2, and 6, the single HF common channel, and intershelter-communications channel 2. These are the channels represented by the eight transmit/receive switches on the channel selector panel (reading from top to bottom) at his position. To transmit/receive on any of these channels, he would simply move the switch of the desired channel to the transmit/receive position. UHF channel 1 and VHF channel 1 are considered his primary channels; the channels used in all control communications under normal conditions. UHF channel 2 and VHF channel 2 are considered as secondary channels, and are used only when transmission/reception cannot be achieved on the primary channels. UHF channel 7 and VHF channel 6 are designated as back-up or guard channels, and are used only in the event of emergencies, or when transmission/reception cannot be achieved on the primary or secondary channels. The channel selector dial at the Pickup Controller's position enables him to select for transmission/reception UHF channels 3, 4, 5, and 6, and VHF channels 3, 4, and 5 -- the seven UHF/VHF channels are not represented by his assigned channel selector switches. The selector dial will be used only under emergency conditions, when communication cannot be achieved or is not practical on any of the six UHF/VHF channels assigned to that position.

The Pickup Controller establishes initial contact with all inbound aircraft. In Figure 21 the probable areas of control responsibility are illustrated to scale. The extreme outer band represents the probable range of the Pickup Controller's area. His control range extends from initial pickup at a maximum tracking acquisition range of 80 miles, through a 360-degree area approximately 20 miles deep. He will usually hand-off aircraft to the Approach Controller at a range of 60 to 70 miles out on a radius line extending from the runway.

Alphanumeric Symbol Acquisition. After initial contact is made with the aircraft and IFF/SIF information is established, the Pickup Controller will select and acquire an alphanumeric tracking symbol to represent the aircraft. This is accomplished using a photoelectric light gun, and the symbol acquisition panel illustrated in Figure 22. The acquisition panel contains sixteen READY indicator lamps, one for each of the sixteen possible track/symbol channels. When a specific track/symbol channel becomes available the indicator lamp will brighten, informing the Pickup Controller that the alphanumeric symbol associated with that channel is available for acquisition. After choosing an available track/symbol channel to represent the aircraft, the Pickup Controller manually points the light gun at the PPI blip indicating the aircraft, and presses the trigger. The light gun projects a small red circle on the face of the cathode ray tube to aid in positioning of the gun barrel on the aircraft PPI blip. When the trigger on the light gun is depressed, the photoelectric cell in the light gun automatically completes the circuit and converts the light from the blip into a video pulse, coincident in time with the appearance of the blip. While the operator is pointing the light gun at the aircraft PPI blip, he simultaneously depresses the ACQUIRE button of the previously chosen track/symbol channel. This determines which of the sixteen track/symbol channel gates, with the corresponding symbol, will move from its "hanger" position to the XY coordinate of the aircraft PPI blip when the video pulse is fed through the acquisition circuit. If the target has been acquired on a particular scan, a small strobe line will appear on or beside the target blip If the target has not been acquired, the process will be repeated throughout the next scan The amber WAIT lamp at the extreme right of the acquisition panel indicates that an acquire button has been depressed on the other acquisition panel at operator position 9.

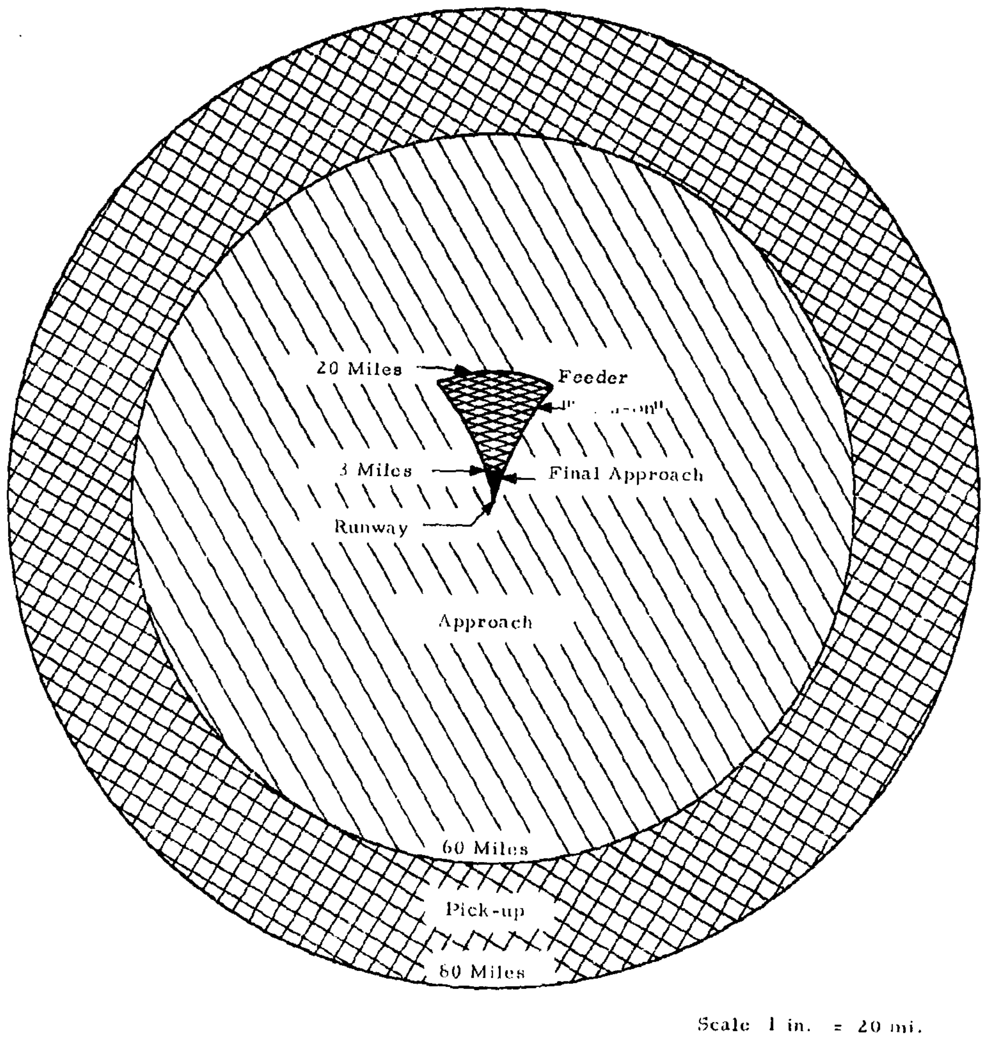


Fig. 21 - Controller Radar Ranges

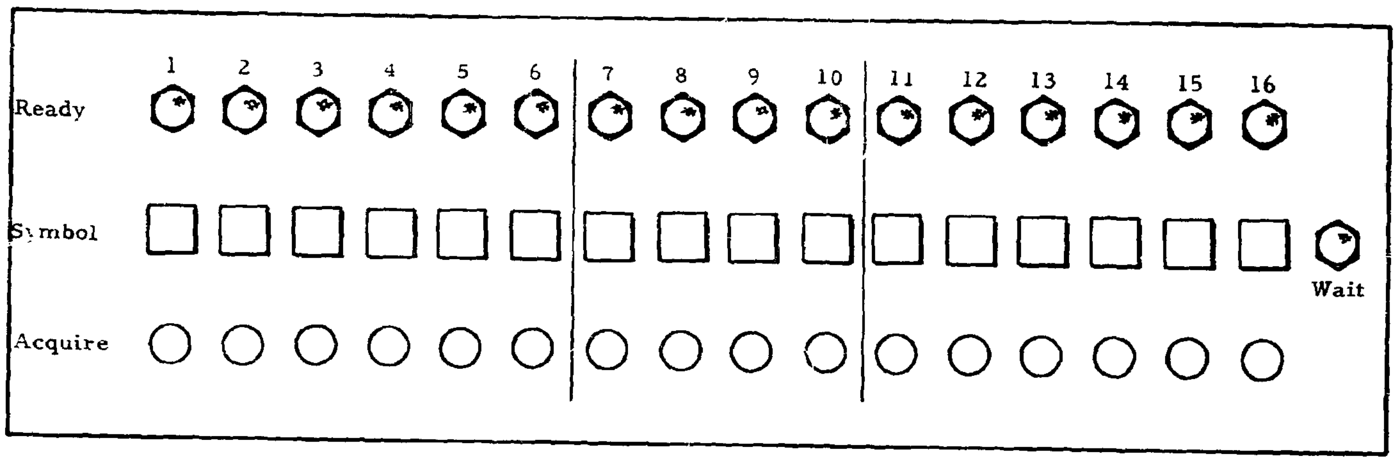


Fig. 22 - Alphanumeric Symbol Acquisition Panel (Operators 1 and 9)

In addition to generating a tracking symbol for each inbound aircraft, the Pickup Controller writes all necessary aircraft information on a card to be used as back-up for the automatic tracking symbols. While the aircraft is in the pickup area, the Pickup Controller confers directly with the Approach Controller on area traffic and desirable headings for inbound aircraft. The Pickup Controller places the aircraft on a heading acceptable for approach control. Hand-off to the Approach Controller occurs when the aircraft is approximately 60 to 70 miles out. The information card is handed to the Approach Assistant who places it in the data board at the horizontal PPI indicator.

b. Position Two - Approach Controller

Functions: The Approach Controller is responsible for the control and separation of air traffic from the point at which they have been picked up and identified until they are ready for transfer to the final approach feeder (or, in the case of overflying aircraft, until they have passed through the control area). His normal area of responsibility is shown in Figure 21. The Approach Controller's major functions include:

(1) Transmitting heading and altitude instructions to pilots to maintain separation.

(2) Informing pilots of unusual conditions -- hazards, or other pertinent information.

(3) Coordinating with both the Pickup and Feeder Controllers to insure a smooth flow of traffic.

(4) Monitoring of aircraft's progress through the control area to insure compliance with instructions and elimination of potential hazards.

(5) Maintaining the aircraft within the tracking system, either by monitoring of the automatic mode or by inserting changes if the manual mode is used.

His control of the aircraft begins upon acceptance of the hand-off from the Pickup Controller. The flight path of the aircraft through the Area Collector's sector, and the final heading of the aircraft at hand-off to the Feeder Controller depends upon information received from both Pickup Controller (e.g. type of aircraft, altitude, heading at hand-off, special conditions such as emergencies, and the amount and types of other traffic in the area at the time) and the Feeder (turn-on) Controller (e.g., traffic conditions, type of approach preferred because of wind, etc.).

The Approach Controller will monitor the path of each aircraft and issue the instruction necessary to effect a safe and expeditious path through his control area. This will require that he will maintain continuing identification of each aircraft under his jurisdiction. This will be accomplished by means of the 16 tracking channels in the symbol group (specifically by means of the track control unit supplemented by the target markers in case this equipment fails or is overloaded.) The Approach Controller will be assisted in this task by the Assistant Approach Controller (see following subsection). The Controller will be further assisted by an overhead projection system which will permit the display of terrain hazards, traffic approach and departure lanes, etc., directly on the CRT surface.*

Air-ground-air communications will be channeled by the communications selector box mounted above the Controller's position and the necessary intercommunications capability will be provided by the appropriate channel on the control box.

The equipment available to the Controller at this station includes: a horizontal 22-inch PPI with associated tracking and symbols coding features (shared with three other controllers); an approach tracking control panel; a communications selector box and microphone/headset; a set of target markers (shrimp boats); a flight data board (actually at the Assistant's station but set up for viewing by the Controller); and an overhead projection system for display of terrain maps and similar data directly on the PPI face

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* This feature is especially desirable in a mobile system where controllers may not have had time to memorize new terrains

Communications: The Approach Controller is assigned UHF channels 2, 1, and 7, VHF channels 2, 7, and 6, the single HF common channel, and intershelter-communications channel 2. These are the channels represented by the eight transmit/receive switches on the horizontal channel selector panel (reading from left to right) located overhead at his position. (See Figure 23). The primary channels at this position are UHF channel 2, and VHF channel 2. The secondary channels are UHF channel 1, and VHF channel 1, while the back-up or guard channels are the same as the Pickup Controller's. The rotary channel selector dial on the Approach Controller's panel provides transmission/reception capability on UHF channels 3, 4, 5, and 6, and VHF channels 3, 4, and 5. The method of operation is similar to that previously described.

Tracking Symbol Control: In tracking the aircraft through his sector, the Approach Controller utilizes the alphanumeric tracking symbols acquired by the Pickup Controller. The track/symbol control panel illustrated in Figure 24 enables the Approach Controller to select manual or automatic symbol tracking. The switches on the control panel provide the Approach Controller and his Assistant with manual control on track/symbol channels 1 through 10, (channels 7 through 10 being shared with the Departure Controllers).

When fully automatic tracking is desired for a specific aircraft, the Approach Controller throws the MANUAL/AUTO mode switch of the track/symbol channel representing that aircraft to the AUTO position. When in the automatic tracking mode, video signals are sampled and fed to an error detector which determines the polarity and amount of error in the gate position. The error reading is then fed through a memory circuit, which will act to reduce the amount of error between the gate center and the video signal to zero, and establish a new tracking gate velocity more closely corresponding to that of the target.

When manual tracking is desired, the Controller throws the mode switch representing the desired track/symbol channel to the MANUAL position. In the manual tracking mode, all video signals are prevented from entering the error detection circuit. The gate maintains the last stored velocity, but is "free" to move off the video signal if any change in the targets X-Y coordinate position should occur. Tracking of the target with the gate is now done manually, using the HEADING dial and the NUDGE pushbuttons on the tracking

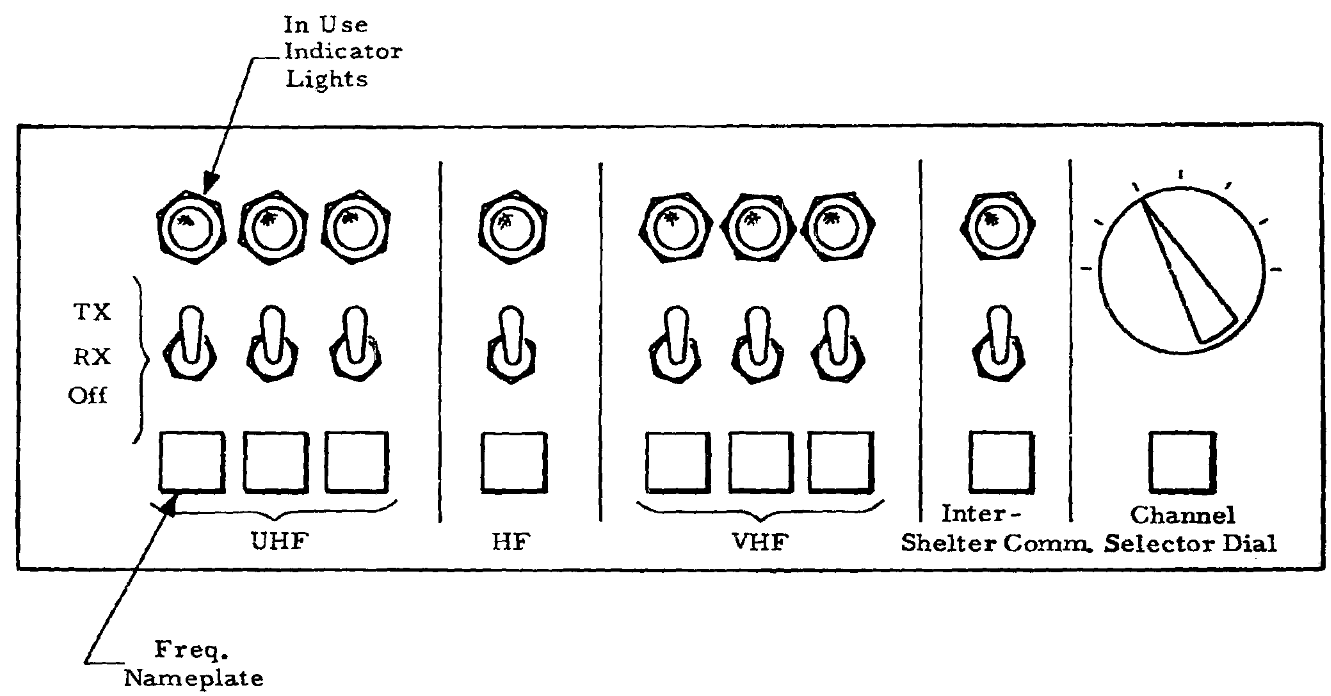

Fig. 23 - Communications Channel Selector Panel (Operators 2, 3, 7, & 8).

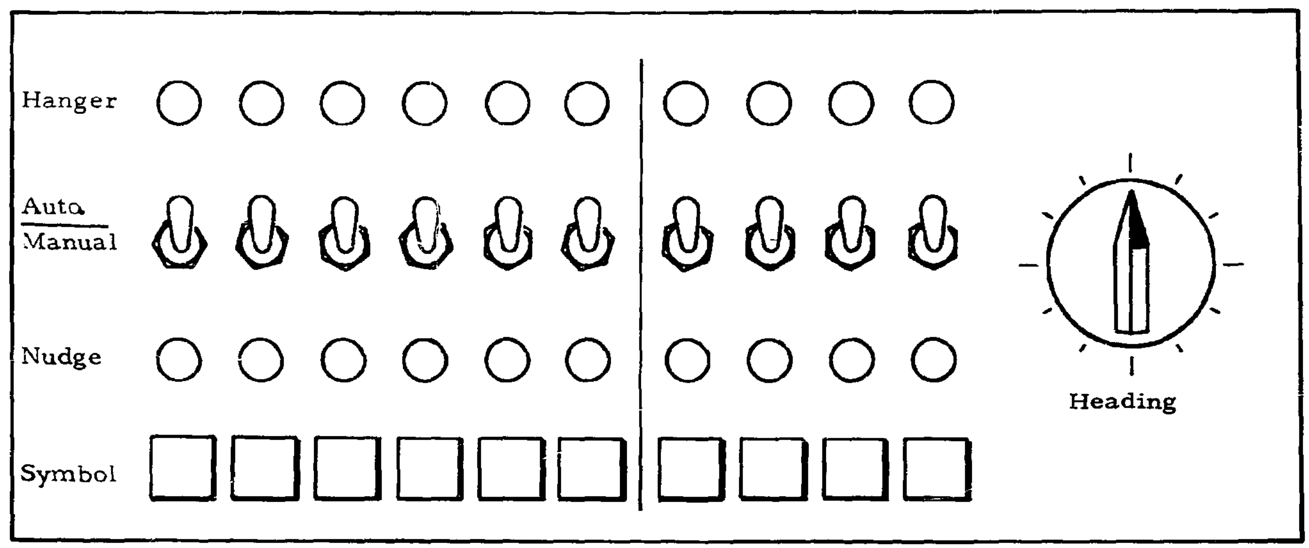

Fig. 24 - Approach Tracking Control Panel.

control panel. Each time one of the NUDGE pushbuttons is depressed, it will cause an incremental change in the X-Y coordinate position of the gate corresponding to that channel. The direction in which the gate will move is determined by the setting of the HEADING dial when the NUDGE pushbutton is depressed. The distance the gate will move each time the NUDGE button is depressed is adjustable from 25 to 200 percent of the gate width.

When an aircraft no longer requires controller tracking, i.e., when landing has been completed, or in the case of departure, when the aircraft is clear of all area traffic, the HANGER pushbutton for the appropriate track/symbol channel is depressed. Activation of this button for any specific track/symbol channel will cause the gate and alphanumeric tracking symbol corresponding to that channel to move to a predetermined "hanger" position. Simultaneously, the READY lamp of that particular channel will brighten on the acquisition panels at operator positions 1 and 9. This track/symbol channel is now ready for reassignment, and the READY indicator lamp remains lit until the corresponding ACQUIRE pushbutton is again depressed at either acquisition panel.

Optical Overlay Projection: Although it is not considered solely as approach equipment, the optical projection unit is used by the Approach Controller, and therefore is included in this subsection. This unit provides Operators 2, 3, 7, and 8 with the capability to project overlay terrain maps onto the face of the horizontal PPI. The projection unit consists of two optical projectors and an ultraviolet projector used to fluoresce the colors of the target markers. Controls for all three projectors are located at operator position 7.

All transparencies for the optical projectors may be fabricated in the field by means of a map-making kit and a 35-mm Polaroid camera. Equipment is provided to permit complete map layout, slide processing, mounting, and alignment of the projectors for congruence with the radar display.

c. Position Three - Assistant Approach Controller

Functions: The general function of the Assistant Approach Controller is to provide assistance to the Approach Controller by compiling, up-dating, and coordinating pertinent information. His primary duties include:

(1) Collecting any available flight plan data.

(2) Posting data on flight progress strips and maintaining the flight progress board.

(3) Communicating with the Pickup Controller regarding anticipated traffic and any unusual conditions.

(4) Assisting the Approach Controller as necessary in maintaining the flow of air-ground-air communications by communicating directly with pilots.

(5) Communicating with other stations which relay pertinent information regarding inbound aircraft.

(6) Communicating with the IFR supervisor to receive any instructions regarding inbound scheduling and information from military or other agencies which may affect inbound aircraft.

(7) Transmitting relevant information to the Supervisor regarding unusual traffic loads, scheduling problems, hazardous conditions, etc.

In addition to the equipment described for the approach control position, the Assistant Controller has his own communications selection panel mounted above his position. He has an equal view of the PPI and access to both the track control panel and the overhead projection system.

Communications: The Approach Controller Assistant's communication channel assignments and selection capabilities are identical with those of the Approach Controller. (See Figure 23).

Data Board: Upon hand-off of aircraft control from the Pickup Controller to the Approach Controller, the Approach Assistant receives the prepared aircraft information card from the Pickup Controller. The Assistant then places the card in the approach half of the data board located between operator positions 3 and 8. The data board is divided into two vertical columns, one for approaching and one for departing aircraft. There are eight data card slots in each column Each card slot has a corresponding illuminated label slot for the insertion of a label showing individual symbols of the symbol group. When the aircraft data card is inserted in the appropriate card slot, the card slot becomes illuminated. When the card is removed the slot becomes dark again, with the symbol label remaining permanently illuminated.

Target Markers: Approximately 24 target markers ("shrimpboats") are provided for back-up use in approach tracking. The markers are small (approximately one-inch long) translucent strips, pointed on one end to indicate the direction of the aircraft flight. In the event of track/symbol channel failure or aircraft traffic overload, the Approach Assistant manually positions the target markers on the face of the cathode ray tube. One marker is assigned to each aircraft, and the markers must be continuously updated manually as the aircraft progresses through the control area. The markers are color coded to aid controllers in distinguishing between aircraft categories such as approach, departure, jet, and prop driven. There are equal numbers of red, green, black, and clear markers. Each marker is printed with a number corresponding to a given data slot on the flight data board. When target markers are used in place of tracking symbols, the marker numbers are inserted in the data board label slots in place of the tracking symbols.

d. Position Four - Feeder Controller

Functions: The general functions of the Feeder Controller is to (1) establish a precise approach pattern for aircraft in the final approach stages, (2) coordinate each aircraft's turn onto the final approach lane, and (3) feed individual aircraft to the PAR Controller for final approach at the proper time, and with the proper heading and altitude. His specific duties include:

(1) Transmission of heading and altitude instructions to pilots to maintain the required separation and pattern.

(2) Informing pilots of their position as requested

(3) Communicating with PAR Controllers regarding the next aircraft in line for precision approach.

(4) Communicating with the Assistant Approach Controller regarding unusual conditions, hand offs, overloads, and approach emergencies.

(5) Communicating with the Assistant Departure Controller to set up appropriate time slots.

The feeder controller position consists primarily of a radar console containing a 22-inch PPI display. The Feeder Controller is supplied with a detachable overhead optical projection system which can be used to superimpose a pictorial overlay directly upon the scope face. This will permit display of the location, pertinent terrain features, hazards, navigational aids, turn lanes, departure corridors, final approach paths and other information.

A headset/microphone, communication selector panel, and land-line terminal are provided for the communication and coordination of functions outlined above.

<u>Communications</u>: The Feeder Controller is assigned UHF channels 3 (primary), 6 (secondary), and 7 (guard); VHF channels 3 (primary), and 6 (secondary and guard), the single HF common channel, and intershelter-communications channel 3. These channels are represented by the eight transmit/receive switches on the channel selector panel (reading from top to bottom) at his position. (See Figure 20). The rotary channel selector dial at this selector panel provides transmission/reception capability on UHF channels 1, 2, 4, and 5, and VHF channels 1, 2, 4, and 5.

The Feeder Controller, as defined in this particular mobile ATC system, is essentially a Turn-on Controller (using the term "turn-on" as traditionally defined in fixed IFR facilities). The Feeder Controller will accept hand-offs from the Approach Controller, and will in turn feed the aircraft to one of the two Final Approach Controllers. When traffic warrants, he will alternate between the two Final Approach Controllers.

Figure 21 illustrates the Feeder Controller's wedge-shaped control sector. Hand-off of aircraft from the Area Controller will occur at a range of approximately 20 miles out from the runway.

<u>Optical Overlay Projector</u>: The projector at this position is essentially the same as that described in operator position 2, with two exceptions. It is detachable, and will be removed when not required. Due to the fact that the

CRT face is tilted towards the vertical at this control position, the projector unit also includes an optical correction system to produce a distortion-free picture congruent with the PPI picture.

e. Positions Five and Six - Final Approach Controllers

Functions: Since the functions and equipments for these two positions are identical, they will be discussed together. The role of a Final Approach Controller is to guide the aircraft down the final approach path to the point of touchdown or visual takeover (at landing minimums). His duties include:

(1) Coordinating instructions from the Feeder Controller.

(2) "Talking" the pilot down: giving him appropriate elevation and azimuth corrections to maintain the correct angle of descent and alignment with the runway.

(3) Transmitting missed approach instructions and deciding whether or not aircraft should "Go Around" in order that a safe approach can be executed.

Under normal and slack traffic conditions only one Final Approach Controller will be employed. When traffic increases, the two Controllers will alternate aircraft. Final control begins upon hand-off of the aircraft from the Feeder Controller, when the aircraft is approximately three miles from touchdown. Control range may be extended out to 20 miles when necessary, with range marks at one-mile intervals on 5-and 10-mile ranges, and at 5-mile intervals on the 20-mile range. Range marks are adjustable to position the touchdown point anywhere between 400 and 6000 feet from the radar set.

The equipments at each position consist of a radar console containing a 10 inch CRT Az-El indicator connected to the PAR subsystem. Each display will include two glide-path cursors independently adjustable to represent different glide path angles or distances to touchdown, a cursor to indicate the safety limits around this path, and two runway cursors (to accommodate two approach courses) adjustable for either right or left of runway approaches. This display, in combination with the standard communication package (headset/microphone, foot switch, and selector panel), will provide the facilities needed for this position.

The major equipment adjustments pertaining to operation (but not alignment) are remoted to the PAR shelter by microwave and can be controlled from either of the controller positions.

Communications: The communications channel assignments for operator positions 5 and 6 are identical, as can be seen in Figure 19. Some difference does occur, however, in the designation of primary and secondary, UHF/VHF channels. The primary channels for Final Approach Controller 1 are UHF channel 4 and VHF channel 4, and his secondary channels are UHF channel 5 and VHF channel 5. The primary channels for Final Approach Controller 2 are UHF channel 5 and VHF channel 5, while his secondary channels are UHF channel 4 and VHF channel 4. The rotary channel selector dial is identical on both channel selector panels. The dial provides transmission/reception capability on UHF channels 1, 2, 3, and 6, and VHF channels 1, 2, and 3.

f. Position Seven - Departure Controller

Functions: The Departure Controller establishes initial contact with departing aircraft, or those executing missed approaches and identifies and vectors these aircraft approximately through the traffic pattern. His duties include:

(1) Coordinating with the Departure Coordinator to obtain departure and missed approach information.

(2) Coordinating with Approach Controller to integrate departures in the traffic pattern.

(3) Communicating with departing aircraft to pass on departure procedure information.

(4) Effecting radar identification and arranging spacings for departing aircraft.

(5) Assuming complete control of any missed approach aircraft and supplying appropriate vectoring instructions.

His equipment and mode of equipment operation is essentially the same as that described for Approach Controller 2 with the exception of the tracking control units which will be similar in design but include channels 7 to 16 instead of 1 to 10.

Communications: The Departure Controller is assigned UHF channels 6 (primary), 3 (secondary), and 7 (guard); VHF channels 6 (primary and guard), and 3 (secondary), the single HF common channel, and intershelter-communications channel 2. Reading from left to right, these are the eight channels represented by the transmit/receive switches on the channel selector panel at this position. The rotary channel selector dial provides communications capability on UHF channels 1, 2, 4, and 5, and VHF channels 1, 2, 4, and 5.

Tracking/Symbol Control: The Departure Controller utilizes the alphanumeric tracking symbols acquired by the Pickup Controller or the Supervisor Coordinator. The track/symbol control panel at the departure position is illustrated in Figure 25. It is identical to the approach control panel, except for channel designation. The Departure Controller utilizes tracking channels 7 through 16, with channels 7 through 10 shared with the Approach Controllers. Operation of the control panel is identical with that of the approach track/symbol panel covered in the Approach Controller subsection above.

g. Position Eight - Assistant Departure Controller

Functions: The Assistant Departure Controller is responsible for aiding the Departure Controller by collecting departure information, maintaining flight progress boards, and coordinating all information relevant to aircraft departure. His duties include:

(1) Collection of all departure flight data by phone or intershelter communications.

(2) Posting of flight strips and maintenance of the flight data board for departures and missed approach aircraft.

(3) Communicating with the tower to issue a radar portion of the ATC clearances prior to aircraft takeoff.

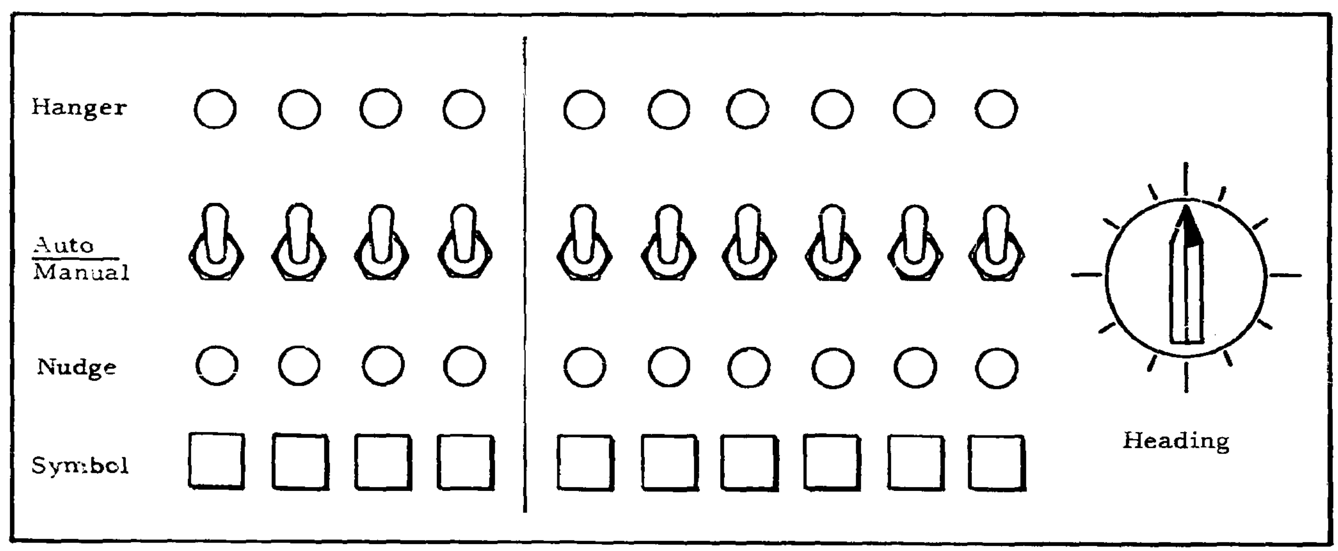

Fig. 25 - Departure Tracking Control Panel.

(4) Communicating with the Departure Controller concerning anticipated departures, missed approach aircraft, hazardous conditions, etc.

(5) Communicating with the Assistant Approach Controller to coordinate departures.

His equipment is essentially similar to that available at the Assistant Approach Controller's station (position 3).

Communications: The Departure Assistant's communications channel assignments are identical with those of the Departure Controller. (See Figure 19).

h. Position Nine - Supervisor Coordinator

Functions: As his title indicates the person at position 9 is responsible for the supervision and coordination of all activities within the IFR shelter and for general liaison with other subsystems. He is provided with the intercommunications, telephone and air-ground-air communications equipment which will permit him to monitor communications anywhere in the shelter and to contact base facilities, other points of the AN/TSQ-47 system, and aircraft in the traffic pattern.

He is also supplied with a PPI console, pickup panel and light gun which permits him to function in the same manner as the Pickup Controller in acquiring aircraft tracks and assigning symbols to them. He can, therefore, serve both as a monitor and as a back-up controller in the event of failure or overload.

The third major function of this position is concerned with operation of the radar control unit which will be routed to the AN/TPS-35 and serve to control or adjust certain of its outputs.

Communications: The communications channels assigned to the Supervisor Coordinator are the same as those of the Pickup Controller, with one exception. The Supervisor is assigned intershelter-communications channel 1. (See Figure 19).

D. AIR TRAFFIC CONTROL CENTRAL, AN/TSW-6 (TOWER)

1. Shelter Layout

The primary factor in determining the location and configuration of equipments in the tower shelter was the need for external visibility from each operating position.

Figures 26, 27, 28 and 29 show the general configuration, equipment layout, and the three possible operator positions. Figure 30 illustrates operator eye positions and the resulting visual area. Since operator visibility was the major consideration, layout was determined for the most part by anthropometric dimensions. The shelter configuration was designed to permit the operator a 360-degree view of the surrounding area, with a minimum total visual angle of 47 degrees (see figure 30). Since this particular shelter is extended for use on the ground or at a maximum height of five feet, the upward visual angle, as taken from a horizontal plane at the eye level, is the most critical. Anthropometric measurements of a population representative of personnel who would be expected to operate this facility revealed that the eye level (as measured from the floor in a seated position) of 95% of the population falls below 51 inches. The visual area of the tower was therefore designed to permit a minimum upward visual angle of 30 degrees for 95% of the operating population. As can be seen from Figure 30, as the eye level height of the operator decreases, the upward visual angle increases, with 50% of the population having an upward visual angle of 33 degrees, and 5% having an upward visual angle of 36 degrees. In general then, an average operator, falling at the 50th percentile of the Air Force population, would have a total visual angle of 48 degrees, and an upward visual angle of 33 degrees.

The operator control console was also designed for maximum efficiency in terms of anthropometric data (see Figure 30). The console height is 30 inches, which is the optimum height for 50% of the population of operators. The working surface of the console is 12 inches deep. This dimension was chosen on the basis of the number and function of operator controls, and the nature of other operator tasks such as writing.

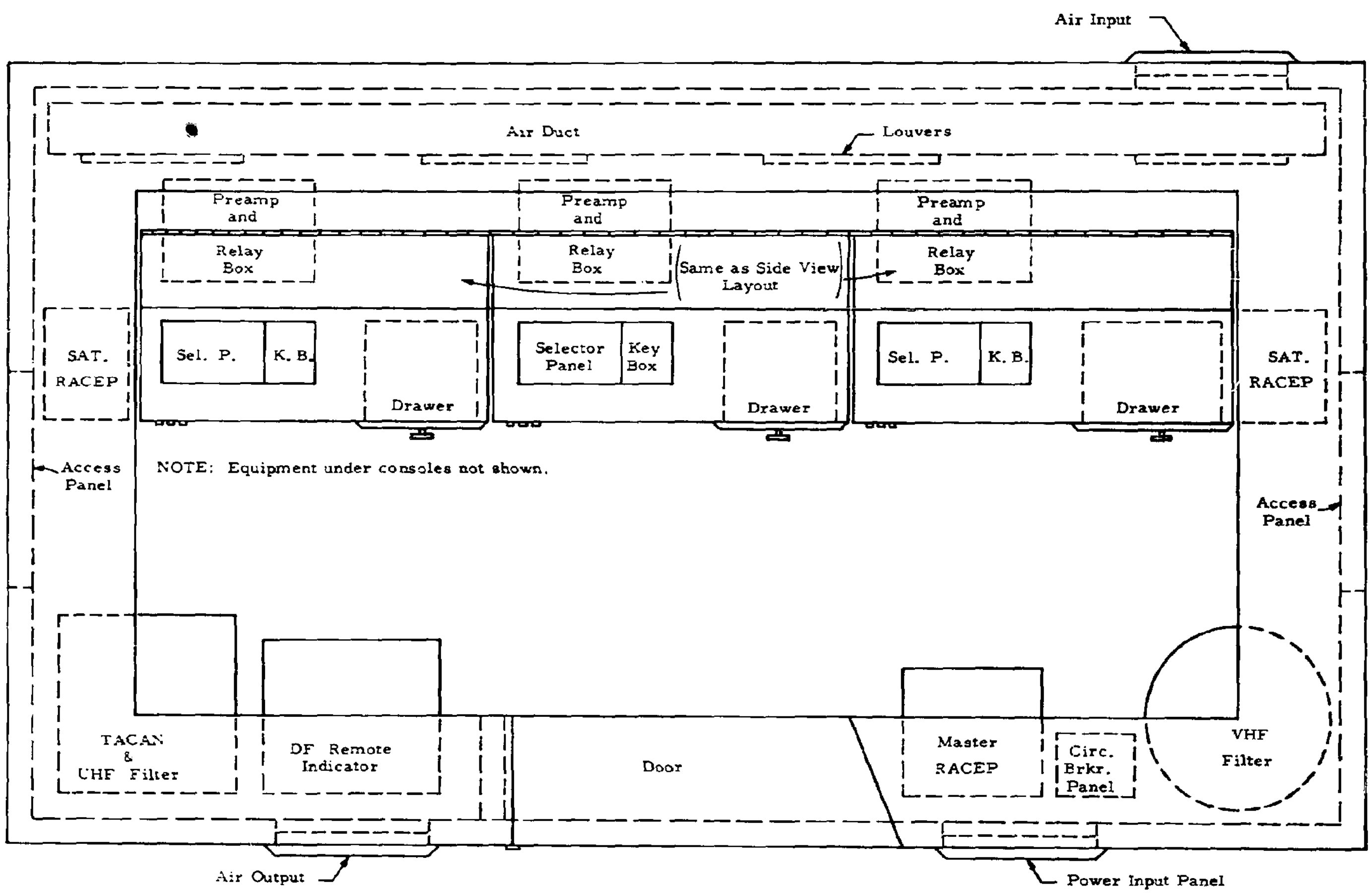

Fig. 26 - AN/TSW-6 Floor Plan.

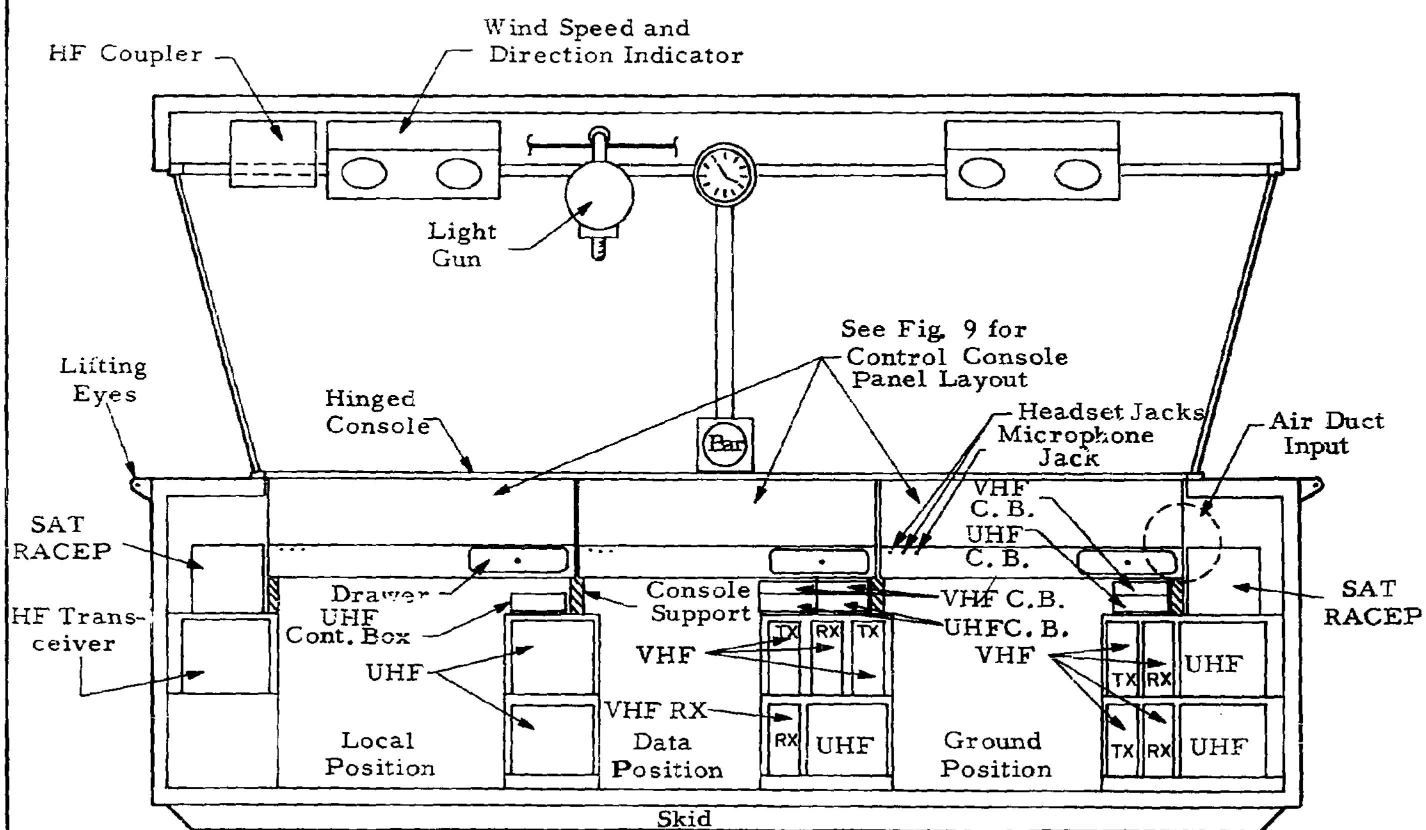

Fig. 27 - AN/TSW-6 Console Wall (Inside View).

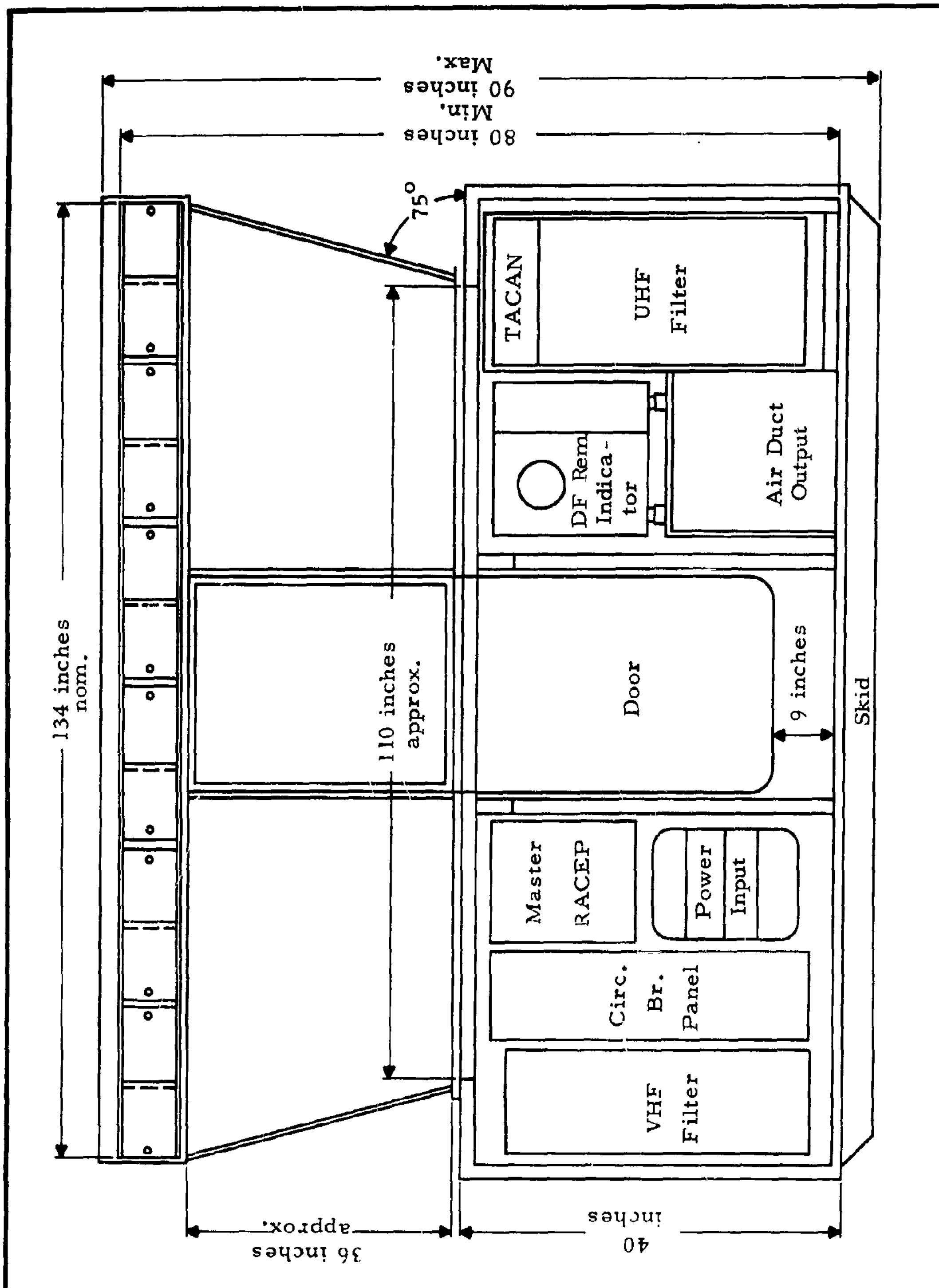

Fig. 28 - AN/TSW-6 Rear Wall (Inside View).

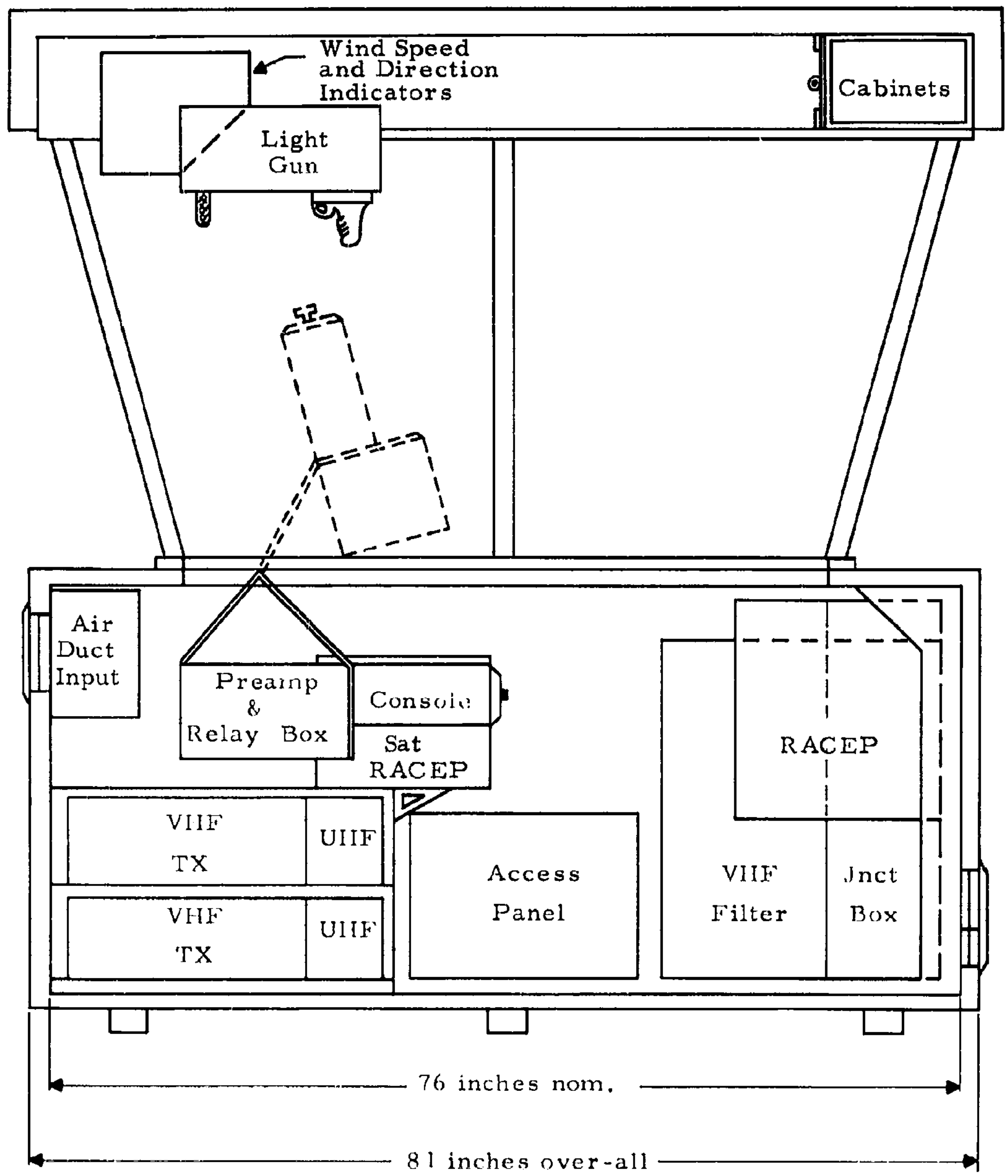

Fig. 29 - AN/TSW-6 Right Wall (Inside Wall).

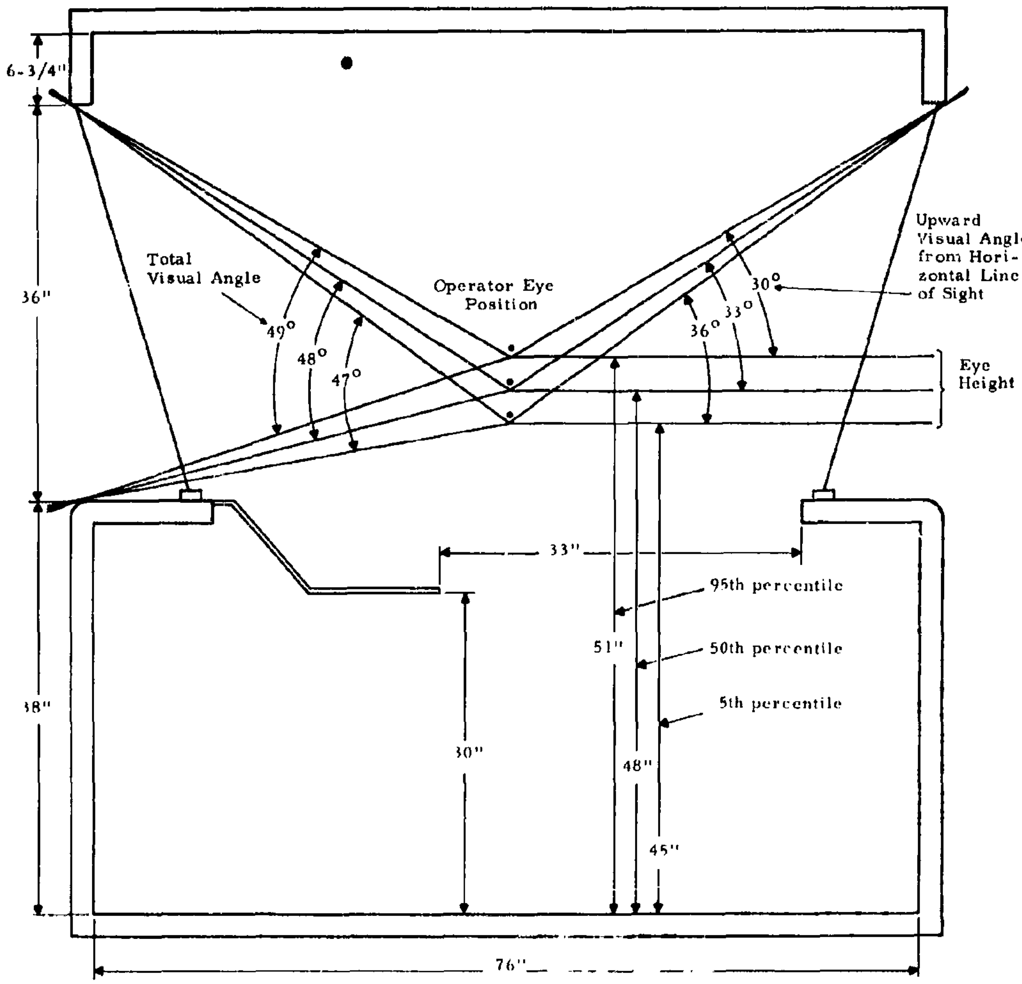

Fig. 30 - Control Tower Shelter End View, Showing Typical Visual Angles.

In view of the excessive amounts of heat produced by the UHF/VHF transceiving equipment, this equipment was located in the area beneath the control console. The concentration of heat-producing equipment in one area enhances air conditioning efficiency by permitting a substantial reduction in the amount of duct work required. Accessibility of the transceiving equipment for maintenance was enhanced by hinging the working surface of the control console to swing upward.

Inclement weather and external temperature changes often produce fogging of the internal window surfaces. This problem was resolved by providing air conditioning duct work sufficient to wash all internal window surfaces with air.

Since auditory communications are vital to the primary functions of this shelter, it will probably be necessary to place a layer of acoustical tile on the ceiling surface to reduce the noise caused by the air conditioning system, other equipments, and the voices of the operators.

During setup and operation, access to the roof of the shelter will be required for antenna installation, adjustment, and maintenance. A 36-inch wide catwalk, surrounding the shelter at the lower edge of the glass area, and a ladder leading from the catwalk to the roof are recommended for this purpose. During transit the ladder will be removed and the catwalk will fold upward and attach at the top of the glass to act as a protective screen for the glass area.

2. Communication Capabilities

There are five UHF transceivers, four VHF transceivers, and one HF transceiver in the VRF tower shelter, providing a total of ten audio channels.

Figure 31 illustrates the antennas necessary to accommodate the ten transceivers. The coupling of four UHF transceivers to one UHF antenna, and three VHF transceivers to one VHF antenna, permits savings in weight, mounting, maintenance, and storage by reducing the total number of antennas to five -- two UHF, two VHF, and one HF whip. This arrangement, however, necessitates the use of one UHF and one VHF filter.

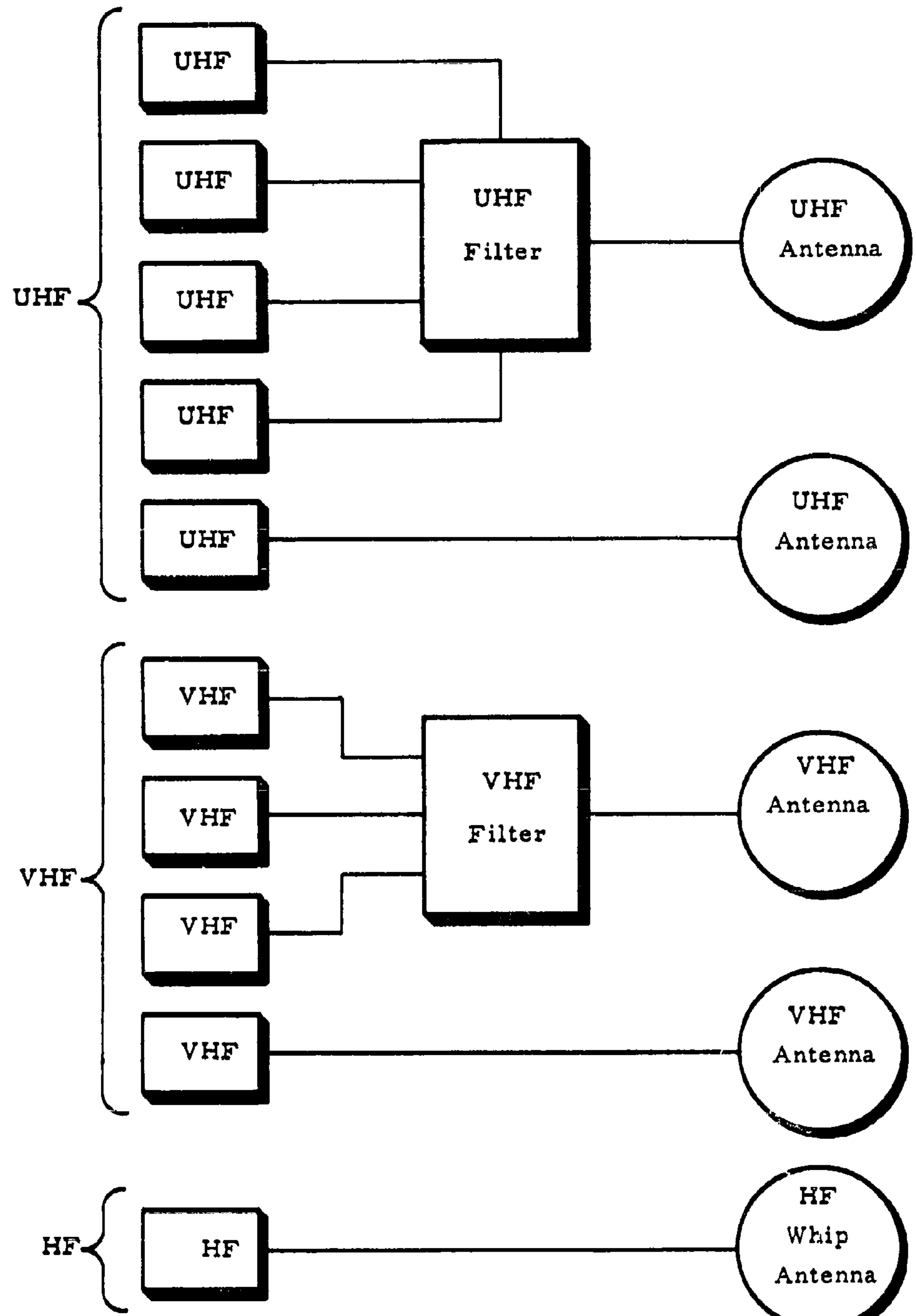

Fig. 31 - Transceiver Antenna Configuration.

In addition to the UHF/VHF air-ground-air facilities, inter-shelter communications facilities are included for exchange of information (e.g., landing clearances) with the PAR or IFR shelters, and also for coordination of traffic flow with other agencies.

Direct communications with other units, for relaying flight data, operational messages, time checks, status reports, and weather, will be possible via HF radio communications when other methods are inoperative or temporarily unavailable.

Subsequent discussion of the operator functions will show that one of the operator positions serves as a data position. The presence of this position allows the VFR tower to serve as a limited IFR facility. The VFR tower facility will also contain UHF DF equipment, which will enable controllers to vector aircraft to the operation location, and to direct instrument let-downs when navigational aids and radars are unavailable.

Figure 32 illustrates the transmitter selector switch control panel, which is identical in all three operator positions. Each of the transmitter selector switches are three-position switches. The UP position provides reception through speakers in the control console, the DOWN position permits reception through headsets, and the middle position acts as a neutral or monitor position, as well as an OFF position. Operators in each of the three positions have identical, dynamic, push-to-talk microphones, and are able to select any of the ten transmitters. Indicator lights, energized in the UP and DOWN positions, are provided on the selector switch panels to show "IN USE" transmitters. Electronic lock-out circuits, also energized in the UP and DOWN positions, prevent (via relay circuits) operation of a single transmitter by any two operators. The first operator making a channel selection (by placing a particular circuit switch in the UP or DOWN position) disconnects the microphone and key lines of the other two stations from the transmitter circuit which he is using, thereby locking out the other two operators.

As a further precaution against inadvertent interruptions or improper channel selection, the switches and "in-use" indicators should be color coded for identification and each speaker also should have an indicator light mounted near it.

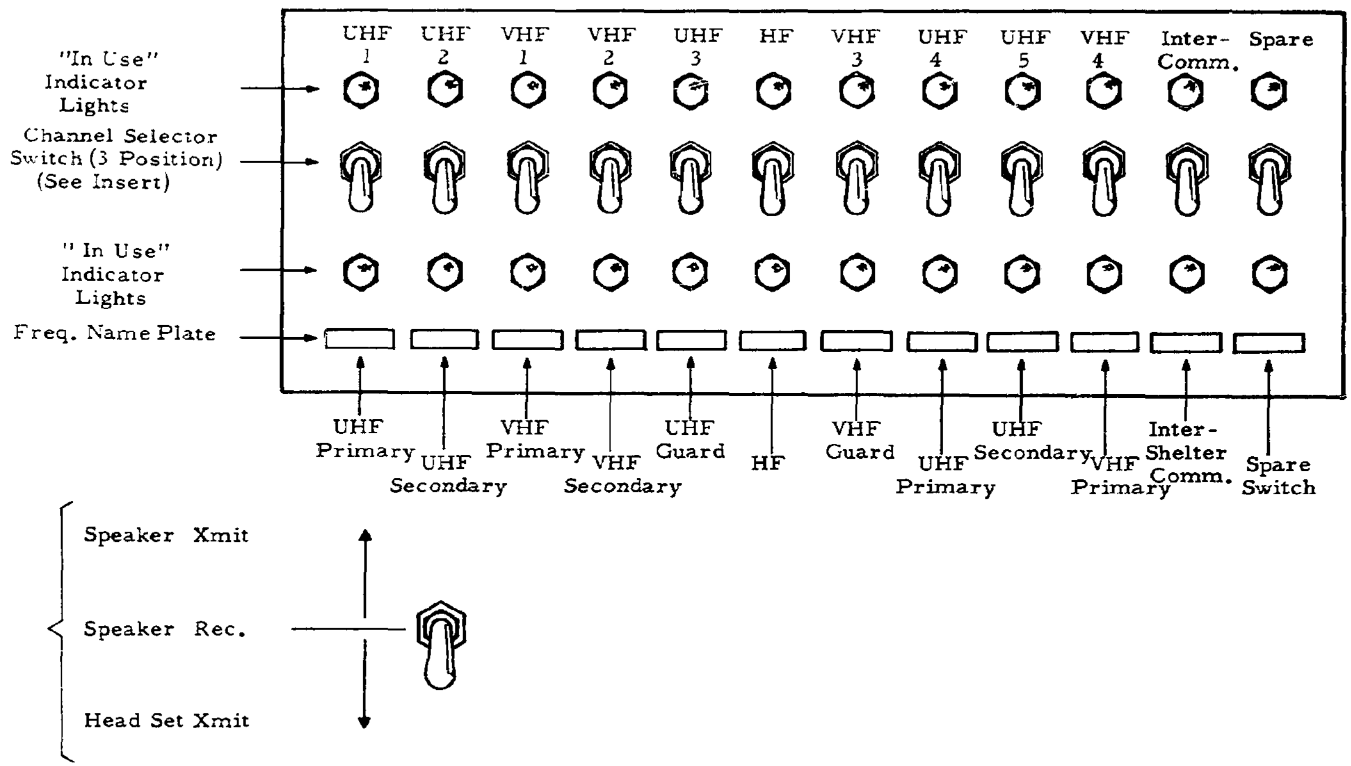

Fig. 32 - Transmitter Selector Switch Panel.

3. Operator Functions

In addition to these transceivers and their associated speakers, control and selector panels, etc., the three tower controllers will be supplied with a DF indicator and plotting board, a flight progress strip board, wind indicators, barometers, a light signal gun, telephone key boxes and handsets, and an AN/TRN-17 TACAN remote control panel. These components will provide tower personnel with the capabilities necessary to perform the functions outlined below.

a. Position One - Local Controller

Normally the operator in this position will act as a Local Controller, and will control all aircraft in the vicinity of the airfield. The specific duties of this position include: (1) Issuance of air traffic control clearances in accordance with applicable regulations. Control responsibility extend to all air traffic and vehicular traffic in or on the landing area, and airc. departing from the control zone. (2) Transmission of essential air tr. fic information to pilots, including field conditions, weather and wind data, altimeter settings, time checks, and D/F headings. (3) Initiation of emergency procedures as necessary.

There are four speakers in the number 1 (local controller) position; a UHF primary, a UHF secondary or backup, a VHF primary, and a VHF secondary or back-up. The four UHF/VHF speakers correspond to switches UHF-1, UHF-2, VHF-1, and VHF-2 on the selector switch panel (Figure 33). These are the four circuits normally operated by Controller One. All of the four UHF/VHF speakers are connected to separate transceivers, with the exception of the VHF secondary speaker which is one of a pair of speakers connected to a single transceiver and activated by a single switch (VHF-2). The second speaker of the pair is in operator position 3, and these two operators (one and three) share the single VHF secondary or back-up transceiver. This shared arrangement is considered adequate due to the decreasing numbers of aircraft equipped with VHF.

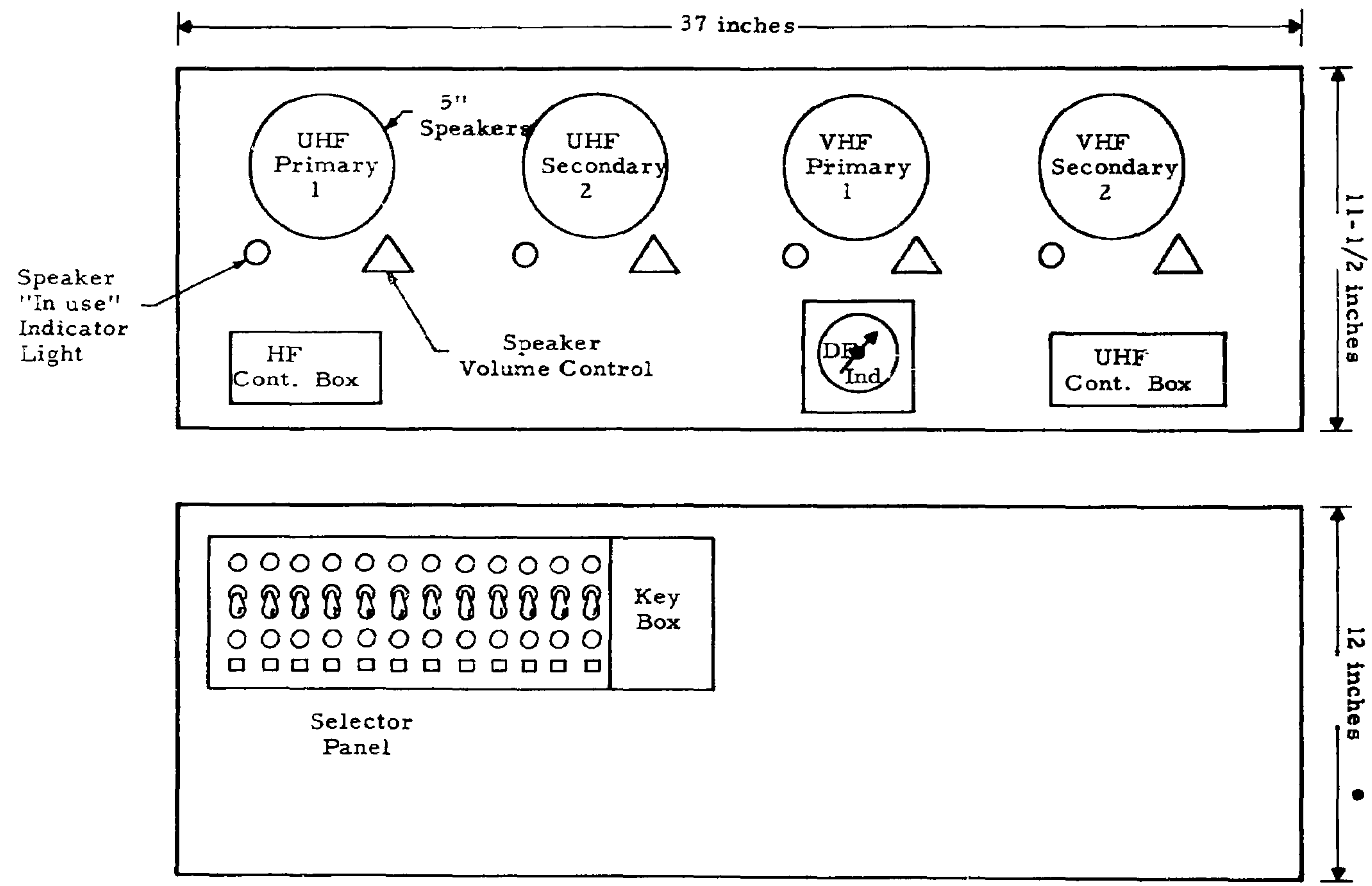

Fig. 33 - Control Console, Operator No. 1 Position

b. Position Two - Data Controller

The operator at position 2 is a data man and will normally act as "bookkeeper" for the other two positions. His main duties consist of: (1) Accepting flight plan information, (2) posting flight plans, position reports, arrival and departure reports on the flight progress strips located in the racks on the face of his speaker panel, (3) acting as communications coordinator for the facility, (4) forwarding clearances, instructions, position reports, etc., as required, (5) using the D/F plotting board, and (6) operating the AN/TRN-17 (TACAN) remote control panel.

There are three speakers in the number 2 (data) position, (see Figure 34), a UHF guard, an HF, and a VHF guard. The two UHF/VHF speakers and the one HF speaker correspond to switches UHF-3, VHF-3, and HF on the selector switch panel, and are the three circuits normally operated by the operator at position 2. The guard transceivers act as emergency frequencies, and may be used to provide UHF/DF information. The single HF transceiver serves as a method of direct communication with other units for the relaying of flight data, operational messages, time checks, status reports, and weather.

c. Position Three - Ground Controller

The operator at position 3 will act as a Ground Controller, and will control all traffic moving on the surface of the airfield. The Ground Controller eases the burden of the local controller position and relieves the congestion on frequencies used to control air traffic. His specific duties are: (1) Issue taxi clearances, field information, current weather, altimeter setting, and time to all departing aircraft, (2) issue taxi instructions to arriving aircraft when such aircraft are clear on the active runway, (3) control all vehicular traffic operating on control landing areas, (4) relay ATC clearances to departing aircraft and receive acknowledgement of such clearances, and (5) initiate emergency procedures as necessary.

There are four speakers at the number 3 (ground controller) position, (Figure 35), a UHF primary, a UHF secondary or back-up, a VHF primary, and a VHF secondary or back-up (the latter sharing

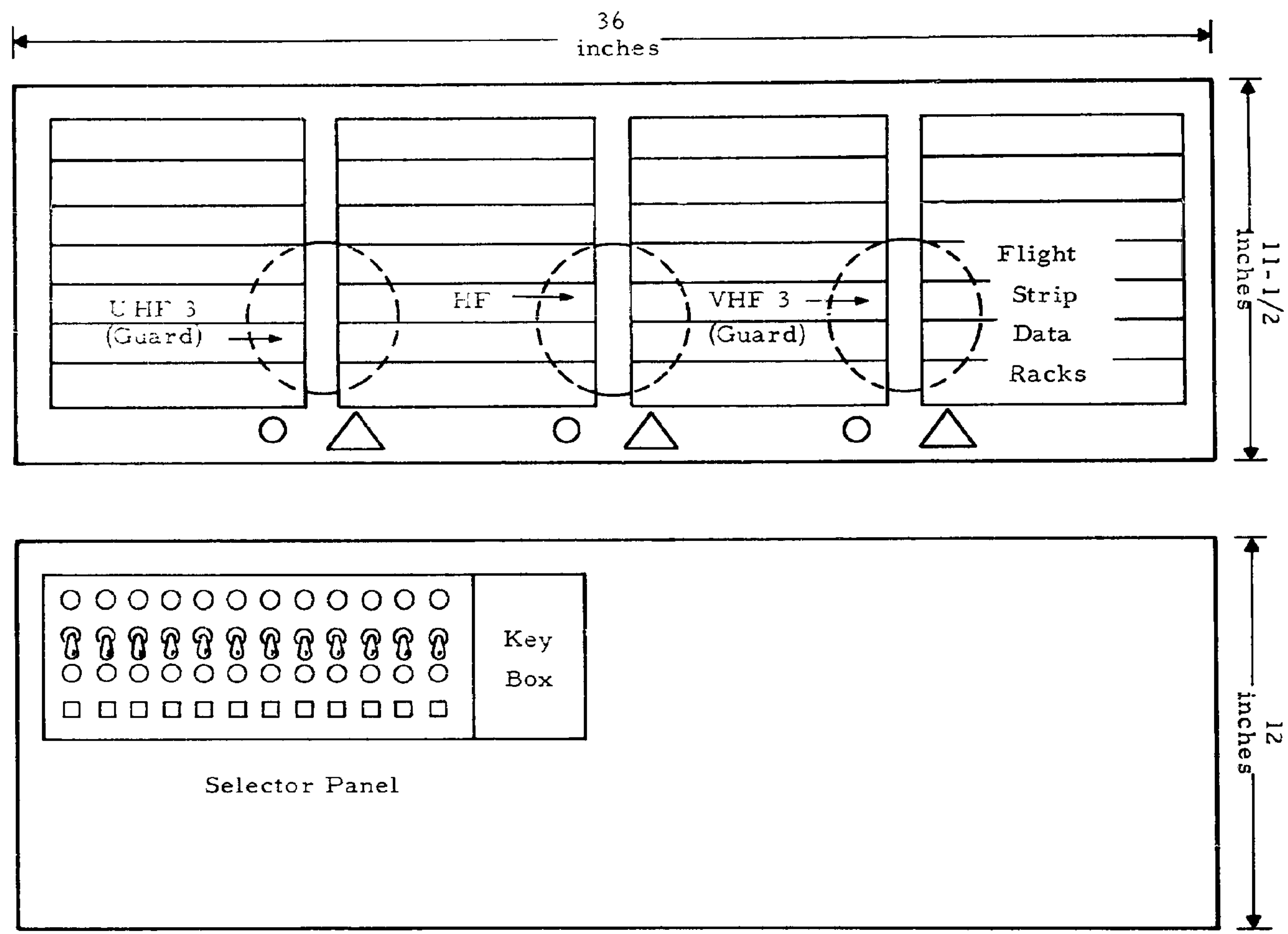

Fig. 34 - Control Console, Operator No. 2 Position.

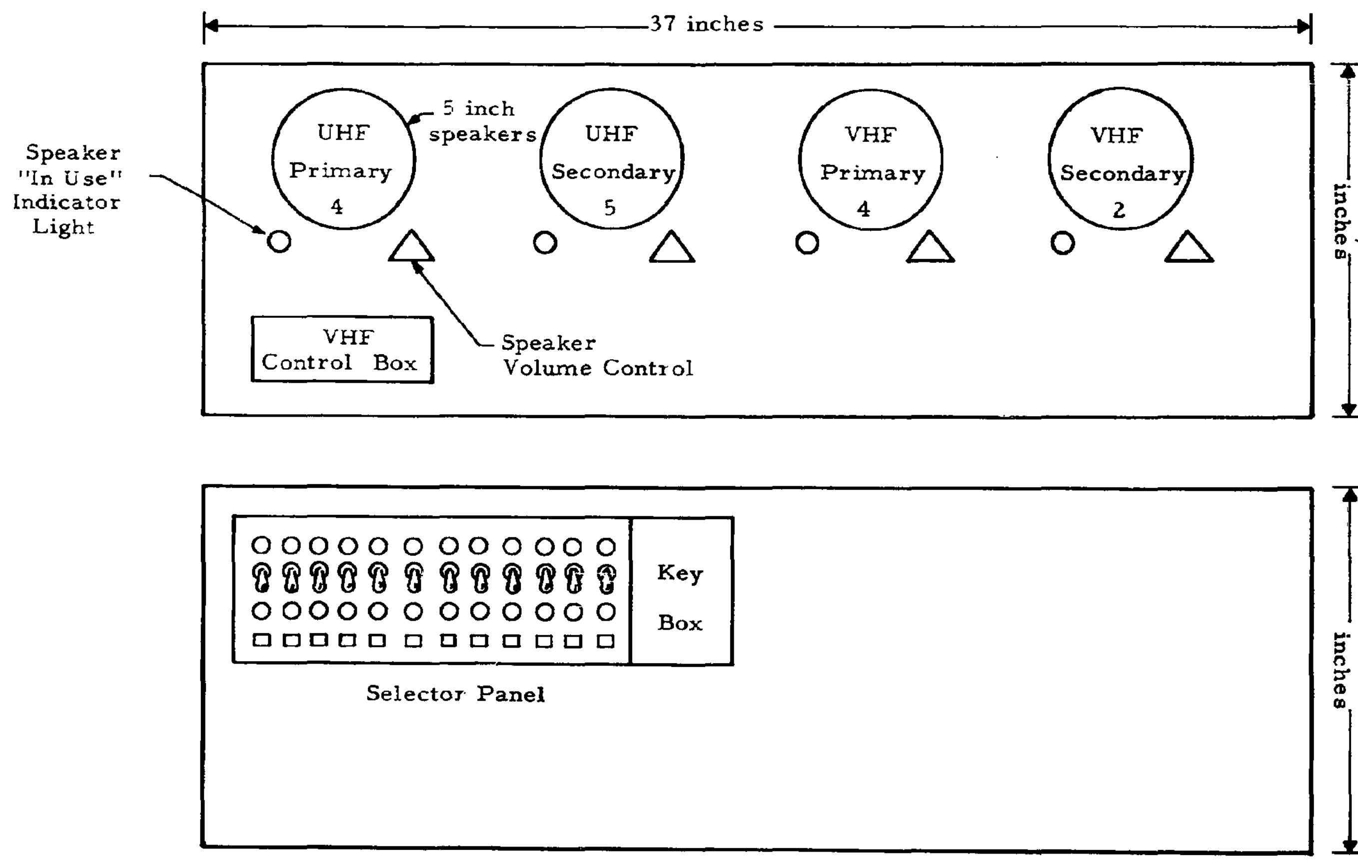

Fig. 35 - Control Console, Operator No. 3 Position.

a single transceiver and selector switch with position 1. The four UHF/VHF speakers at this position correspond to switches UHF-4, UHF-5, VHF-4, and VHF-2 on the selector switch panel, and are the four circuits normally operated by the controller at position 3.

E. PAR (PRECISION APPROACH RADAR) SHELTER (AN/TPN-14)

1. Shelter Layout

In achieving an adequate layout for the PAR shelter, primary consideration was given to the personnel functions likely to occur during operation and maintenance, and secondary consideration to provide an adequate storage area for the necessary antennas during transit. The present layout of equipment (shown in Figures 36, 37, and 38) offers the best solution to these operational and storage problems.

Maintenance is one of the primary functions to be performed, and a large, well-lighted work surface is provided for this purpose. The total work surface area was designed to accommodate the largest piece of equipment housed in the shelter. The work table folds flat against the wall to facilitate antenna storage, and is 35 inches high when in working position (the optimum height for a standing bench operation). The work table was placed along the wall to allow maximum operator work area, and to provide adequate pull-out space for the UHF/VHF transceiving equipment stored beneath the table.

The PAR indicator was located in the corner to allow efficient operation without interfering with the maintenance functions of the shelter.

2. Communication Capabilities

Communication capabilities in the PAR shelter include UHF/VHF air-ground-air communications and the inter-communication system. The UHF/VHF air-ground-air communications will serve for emergency final approach control should the IFR facility become inoperative, or in the event of deployment to a satellite air field. The intercommunication system will provide both a link with the tower (for coordination of emergency clearances), and a link with the IFR shelter (for initial coordination of radar and indicator alignment, coordination of major and minor adjustments, and maintenance).

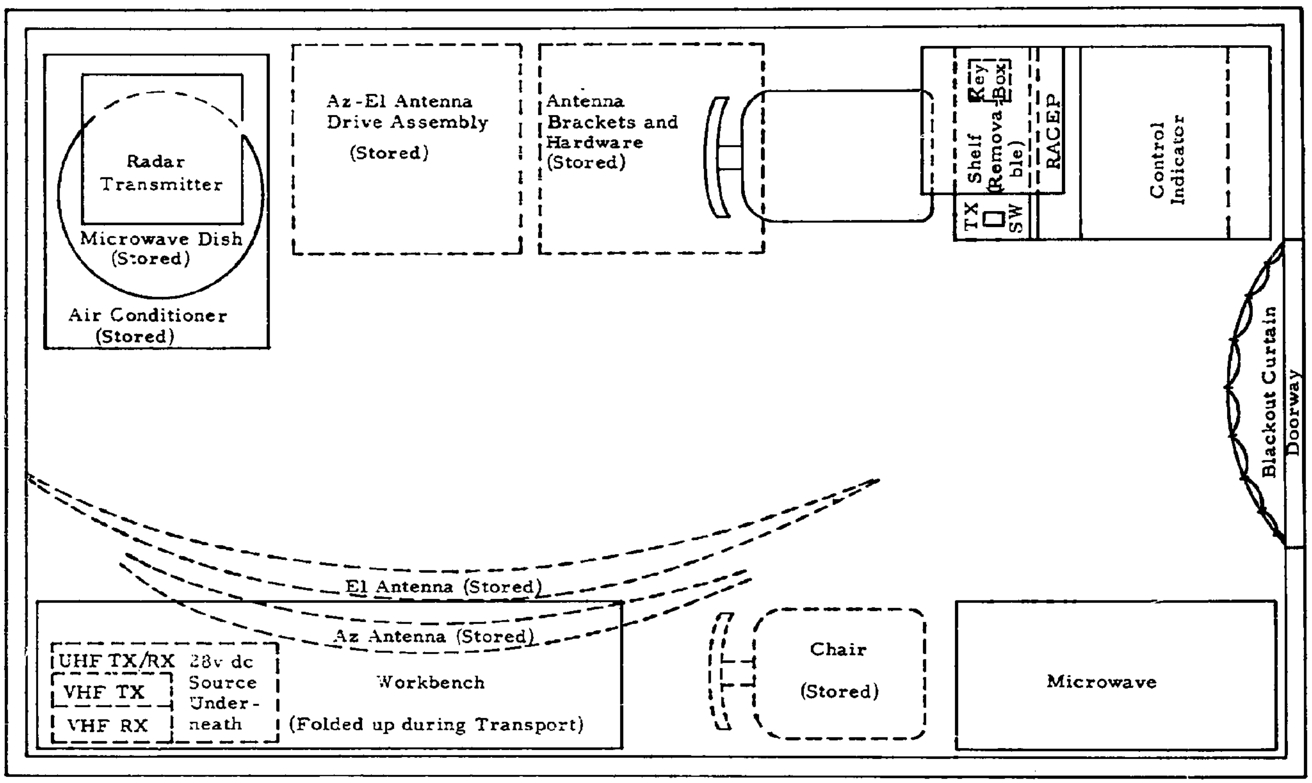

Fig. 36 - PAR (Precision Research Radar) Shelter, Floor Plan.

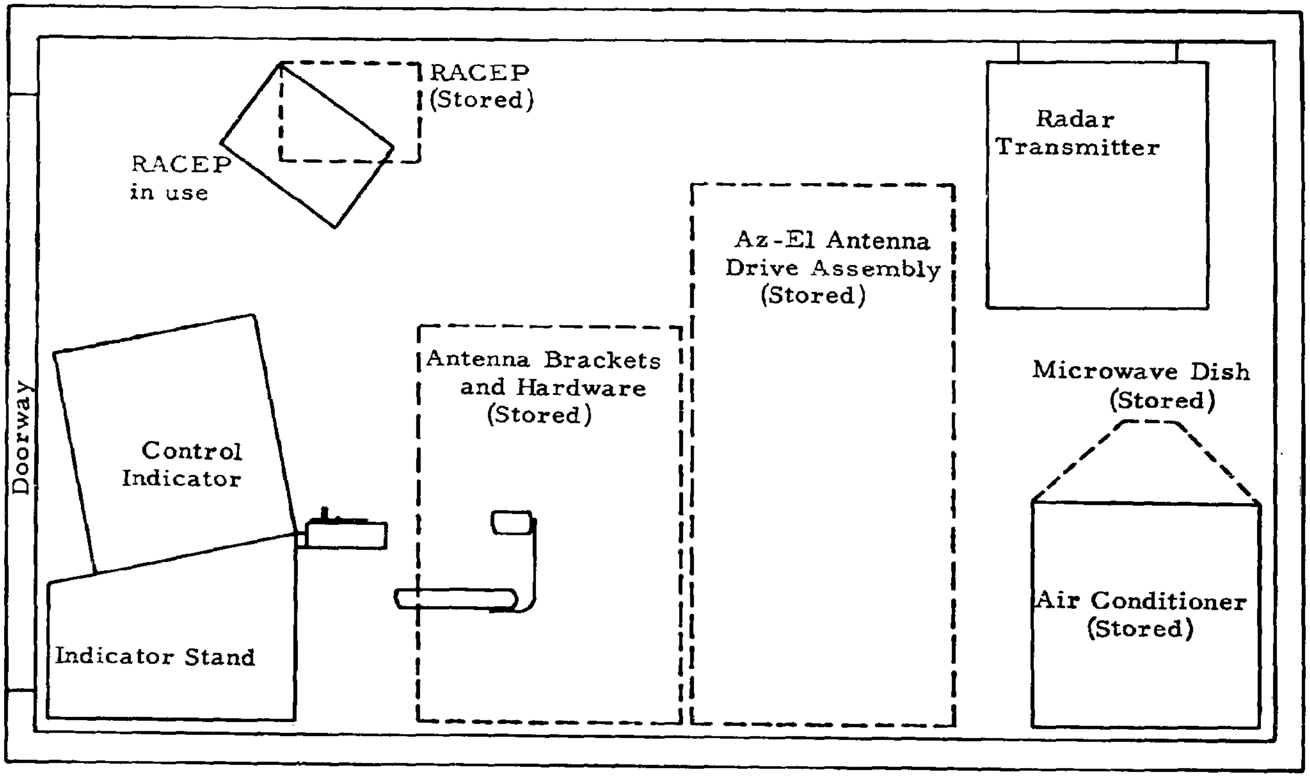

Fig. 37 - PAR Shelter, Interior View (Right Side)

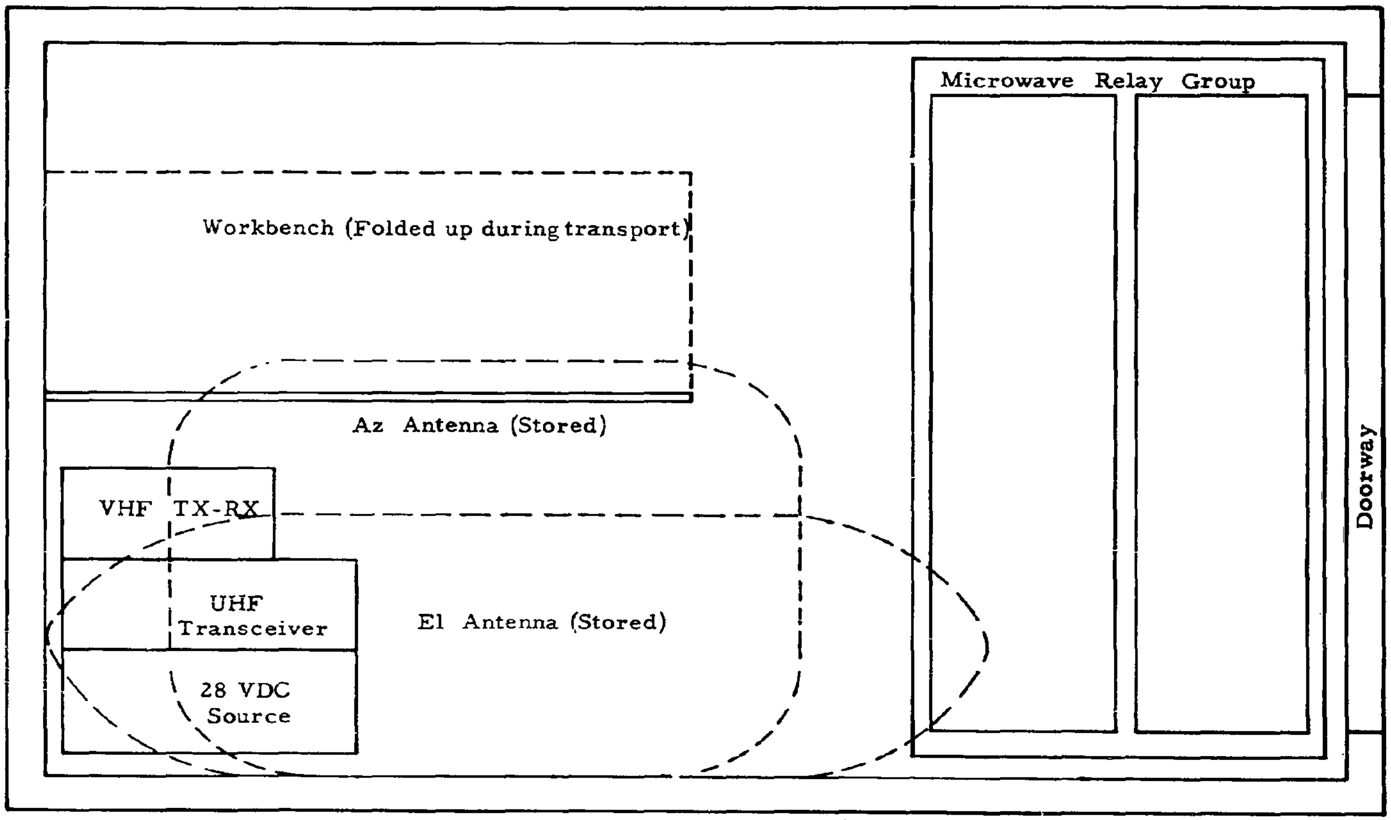

Fig. 38 - PAR Shelter, Interior View (Left Side)

3. Operator Functions

Normal setup and operation of the PAR facility requires only one operator, with the exception of antenna installation which may require temporary extra help.

The radar technician in the PAR shelter will begin setup procedures for operation by siting the equipment in relation to the runways which are being used for radar controlled landings. The next step involves assembling the equipment and installation of antennas and drive assemblies. Once the site is selected and the antennas installed, the runway centerline, touchdown point, and runway parallel are marked with the siting target reflectors. After placement of the target reflectors, the radar set is oriented and aligned to each different runway by means of a telescopic sight.

Following this alignment, the technician commences with the turn-on procedure, tune-up, and cursor alignment. The course-line cursor is aligned using the return signals from the runway center reflectors; the glidepath cursor aligned using the touchdown reflectors; and the approach angle of the azimuth course-line cursor aligned with the runway parallel reflector. This cursor alignment procedure is carried out for all runways to be used. After cursor alignment is completed, the CRT display is adjusted for intensity, focus, video gain, centering, IF gain, AZ and EL control, LO tune, AZ tilt, EL target, mode, range, altitude, pulsewidth, glidepath angle, etc.

During the turn-on and tune-up phases, constant contact will be maintained with the controllers at the PAR indicators in the IFR shelter. As in the case of the surveillance radar, minor adjustments may be made at slaved indicators in the IFR shelter, but the major adjustments must be made by the technician in the PAR shelter.

Under emergency conditions (e.g., if the microwave equipment and/or cable links of the IFR facility were inoperative), the equipments in the PAR shelter must be capable of directing precision approach landings. Under these conditions the controller would operate from the PAR facility, and the landing rate would be greatly reduced since the necessary transfer of control from the Feeder position to the PAR controller would have to occur over the intercommunications system.

F. ASR (SURVEILLANCE RADAR) SHELTER (AN/TPS-35)

1. Shelter Layout

The specification of an adequate layout for the surveillance radar involves consideration of the personnel functions that are likely to occur during operation, and the quantity, size and characteristics of the equipment. The equipment required for this shelter is large in size and volume (relative to the total area available for packaging) and has many peculiarities, but, fortunately, the personnel activities do not require an excessively controlled environment.

By grouping the receiver, main power supply, modulator transmitter, and modulator transmitter power supply together, the air conditioning loads are simplified, and antenna locations are optimized without compromising design for maintainability. Further, this grouping leaves a relatively uncluttered area for maintenance and operational activities, and permits open access to the microwave equipment, which may require frequent adjustment. The suggested layouts are shown in Figures 39, 40 and 41.

The initial alignment of the radar involves the indicator but not necessarily the electronic counter-countermeasures (ECCM) equipment. However, once the operation has proceeded beyond this initial step, the ECCM equipment and the indicator are employed jointly in anti-jamming activities. The ECCM equipment and the indicator are grouped together to permit ease of operation under these conditions. Since the ECCM equipment is the less frequently used of these equipments, it was located above the radar indicator. This places the indicator in the prime visual and manual reach areas of normal operators, yet keeps the ECCM equipment well within the boundaries of efficient workspace.

Since this shelter must contain facilities for equipment maintenance, a large, well lighted work surface is provided. The work table in this area collapses to provide space for antenna storage during transit.

2. Communication Capabilities

The communication equipment in the surveillance radar shelter will be limited to the intercommunication system and one UHF transceiver.

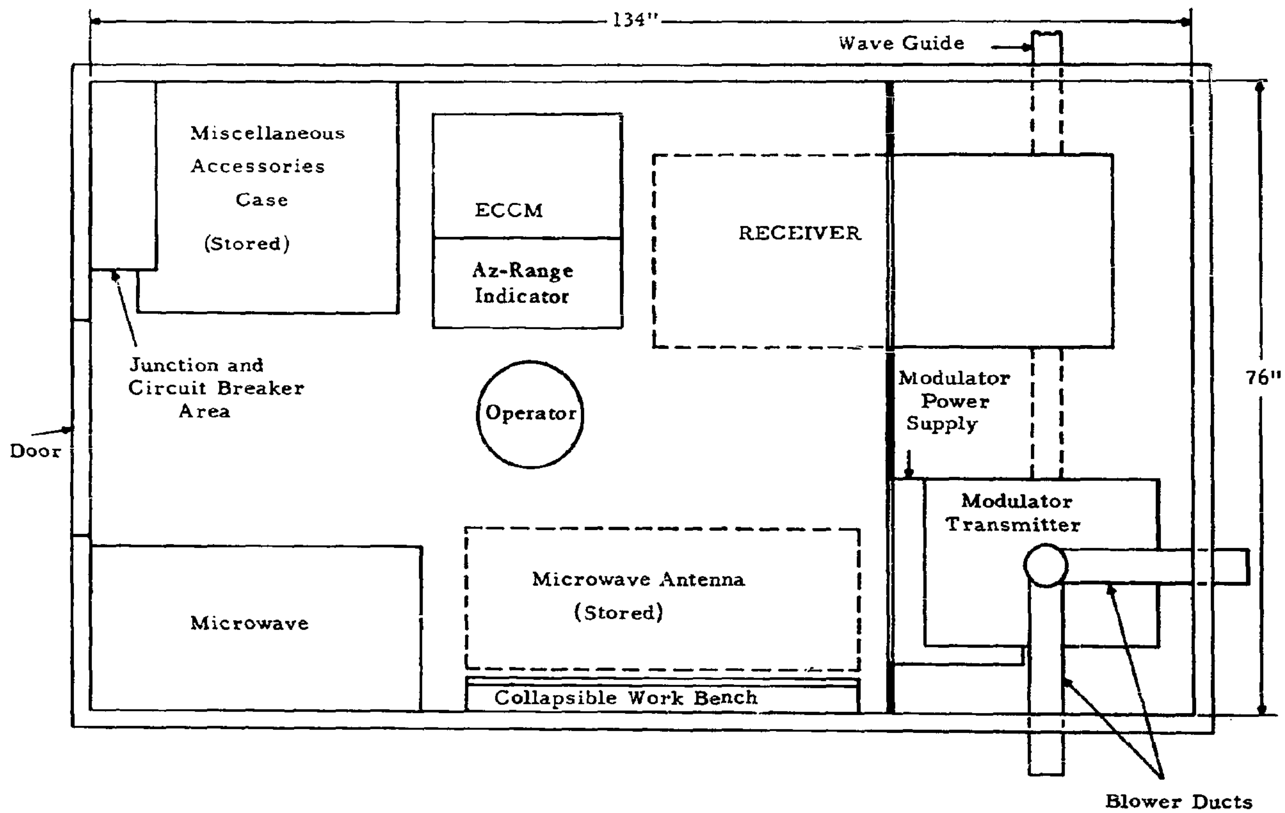

Fig. 39 - ASR (Surveillance Radar) Shelter, Floor Plan.

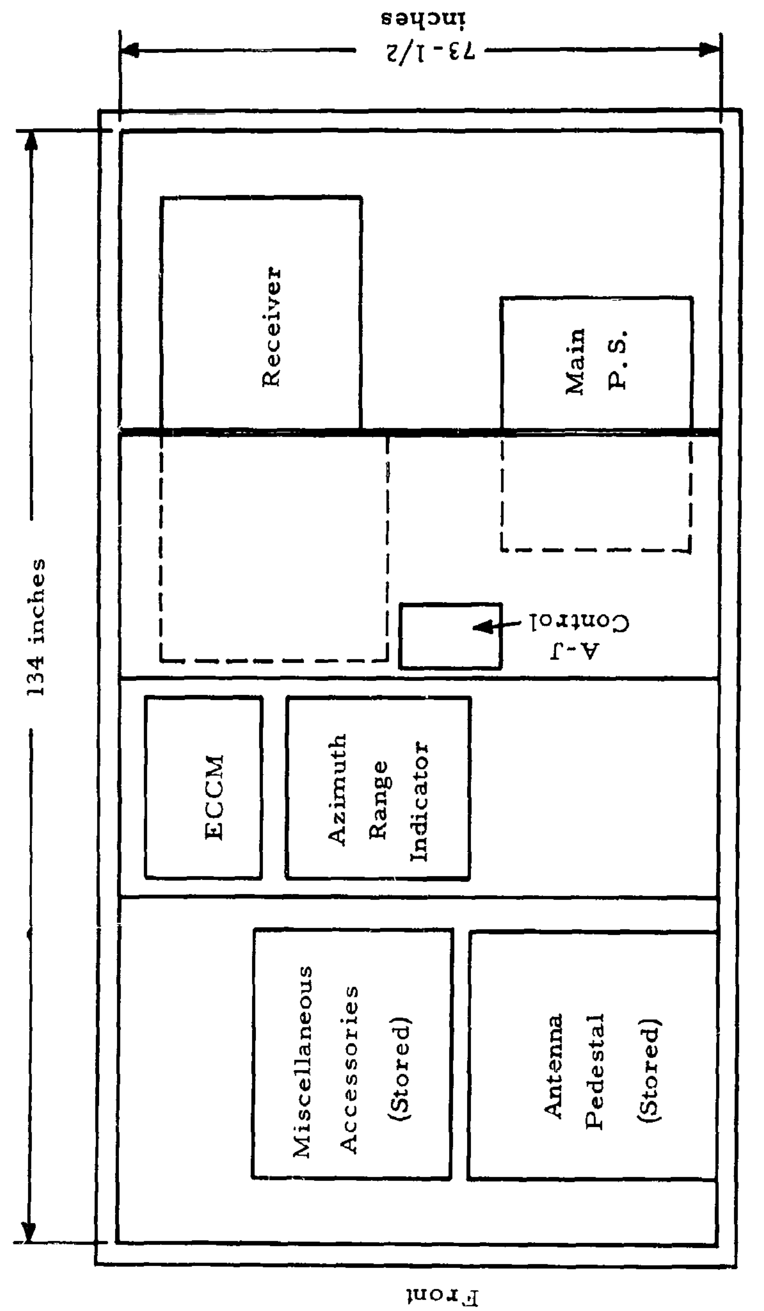

Fig. 40 - ASR (Surveillance Radar) Shelter, Left Side View.

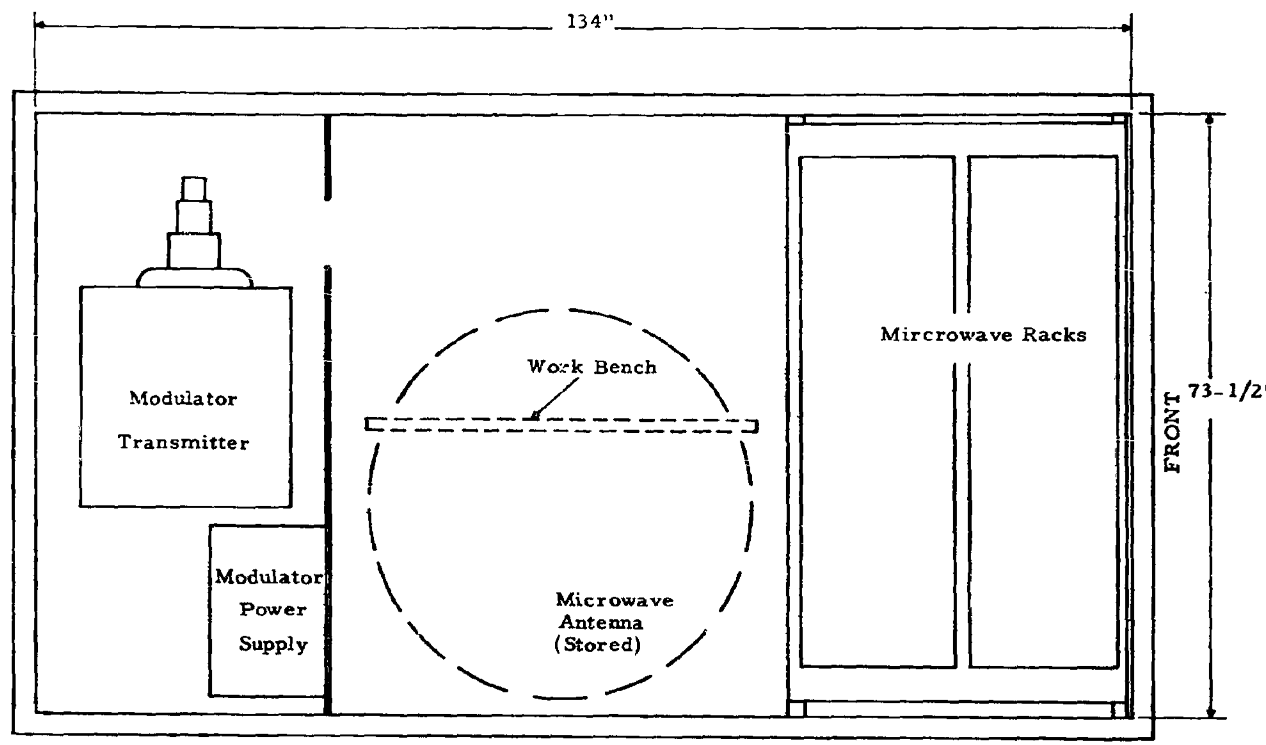

Fig. 41 - ASR (Surveillance Radar) Shelter, Right Side View.

The intershelter communications link is invaluable for effective system performance since it will be used to coordinate the initial radar and indicator alignment. During system operation, it is used as a link between controllers in the IFR shelter and maintenance personnel in the surveillance radar shelter to coordinate subsequent readjustments.

All ECCM operations will be controlled over the intercommunication system when the need for such measures arises. The probable steps involved in both radar and ECCM operations are discussed in the following subsection.

3. Operator Functions

Only one operator position containing a 3-inch "A"-scope monitor and a 10-inch PPI will be required for normal operation of the surveillance radar facility. However, during setup some extra help will be required for positioning the antennas because of their weight and installation location.

The radar technician in the surveillance shelter will begin operation by aligning and adjusting the radar. During this phase, constant contact will be maintained with the controllers who operate the surveillance indicators in the IFR facility. "Convenience" adjustments (e.g., gain brightness) may be made at the slaved indicators in the IFR shelter and at the radar control unit located at position 9. Some major adjustments will not be remoted and therefore will have to be made by the technician in the surveillance shelter.

The purpose of these adjustments will be to remove as much information distortion as possible. The major source of distortion will most probably arise from the microwave link, but additional distortion can also be caused by a poorly adjusted slave indicator, or from poor adjustment of the primary radar indicator.

The ECCM equipment will contain a series of pre-set fixes to combat jamming. Each will be controlled by a switch, and operation will be relatively simple. The complications arise in the decision-making process, which determines which fix or combination of fixes should be employed for anti-jamming.

This process consists of the following steps: (1) determination that jamming is occurring, (2) assessment of the characteristics of the jamming signal, (3) decision as to which fix or fixes to employ as anti-jamming measures, and (4) evaluation of the effectiveness of the anti-jamming fixes that were employed,and implementation of any changes in ECCM strategy to increase anti-jam effectiveness.

The first step is a "go-no-go" decision that the radar either is or is not being jammed. It is possible that the controllers may be the first to perceive the effects of jamming, in which case they would notify the technician in the surveillance shelter and wait for his action. However, there is a much higher probability that the technician will become aware of the presence of jamming signals at least as soon as the operator and attempt to correct the situation. In either case, the controller in the IFR shelter can actively participate only in the first step in the decision-making process. From this point on, only the technician in the radar shelter has the equipment necessary to employ ECCM.

Once it has been decided that the radar is being influenced by jamming signals, the technician, with the aid of an A-scope,must assess the characteristics of the jamming signal. Then he can decide which fix(es) he should employ to counter the jamming signal. The next step then is to evaluate the ECCM strategy employed by determining whether or not the effects of the jamming signal are overcome, and to continue the ECCM operation until an adequate counter-countermeasure is obtained.

G. PROFICIENCY SHELTER

The proficiency shelter will be added to the AN/TSQ-47 system as part of a supplementary package to be included in a later procurement. Since the complete hardware and functional specifications for this facility are still in the process of being developed, this report will deal primarily with the philosophy, purpose, and use of a proficiency shelter. The following subsections describe the system, the operational and physical requirements for such a shelter, and the possible alternative approaches which might be employed.

1. System Requirements

The first step in determining the nature of a proficiency shelter involves the specification of user and system requirements and limitations. These will form the basis for subsequent planning and evaluation of alternate approaches. The proficiency shelter, as currently conceived, will provide the mobile AFCS squadrons with a controller practice and check-out capability. Specifically, the three major functions of the proficiency shelter will be:

(1) to permit on-the-job evaluation of the capabilities and skill levels of men assigned to the mobile squadrons. (While not primarily intended for a training device, some training value will accrue through its use; the main purpose will be to assess the state of training and proficiency).

(2) to orient experienced personnel, newly assigned to mobile squadrons, to the operations and conditions peculiar to the mobile system.

(3) to provide practice for mobile squadron personnel during periods of relative inactivity or between deployments, and to orient them to the changes involved in shifting from one site to another (e.g., location of geographical landmarks and hazards, traffic patterns, location of beacons and other navigational aids, etc.).

2. Tasks To Be Included

The AN/TSQ-47 system consists of several diverse subsystems, which, in turn, require many different operations and operator tasks. One of the first steps in delineating the requirements for a proficiency shelter is to specify the distinct operator tasks and functions which are to be included within the scope of the facility. For this purpose it is not necessary to describe the operator tasks in terms of their psychological components (e.g., reaction time, perceptual span, informational storage capacities, etc.) but rather in terms of discrete behavioral operations such as target detection, target identification and coding, communications, manipulation of controls, etc.

If we restrict the scope of this facility to operational tasks (as opposed to maintenance tasks described in Section I below) we are still left with 19 separate operator/controller stations and 15 distinct sets of operator duties. Since this number is still much too large to be handled by a mobile proficiency shelter, it will be necessary to restrict the scope of the shelter to a selected group of critical tasks.

In order to be consistent with the purposes listed above, this selection of critical tasks should be based upon multiple criteria consisting of: task complexity (in a psychological sense), importance to system operation; relative transfer of training and practice from other equipments to the AN/TSQ-47 (the less the transfer, the greater the need for practice on the task); the degree to which task elements are influenced by changes in the geographical environment and/or operational philosophy, and the general nature of the practice and the performance criteria applicable to each task.

Consideration of these criteria (see Figure 42) indicates that the major emphasis of the proficiency shelter should be focused upon the tasks performed by personnel in the IFR facility. The duties of operators in the tower and communications shelters differ from corresponding operations in fixed facilities, mainly in terms of psychomotor functions, which are changed as a result of differences in equipment location and layout. The practice of these skills requires the use of either actual panels and consoles or extremely detailed and realistic mock-ups, but does not require external signals or other complex dynamic inputs. The tasks of IFR personnel, however, are such that dynamic targets are necessary to provide adequate practice and evaluation. The specific tasks or situations to be included in the proficiency subsystem would include:

(a) Target detection

(b) Target identification and tracking

(c) Initial planning of aircraft paths and hand-off points

(d) A-G-A communications

	TOWER SHELTER	COMMUNICATIONS SHELTER	IFR SHELTER
TASKS - COMPONENTS	Procedures Psychomotor Voice Communications Information Storage and Transmission Decision Making	Procedures Psychomotor Voice Communications	Procedures Psychomotor Voice Communications Information Storage and Transmission Decision Making Tracing
IMPORTANCE OF SPEED AND ACCURACY	Very important to adequacy of system performance	Important, but the consequences may not be as drastic	Very important to adequacy of system performance
RELATIVE TRANSFER	High, except for psychomotor tasks	High, except for psychomotor tasks	High for Voice Communications and Decision Making. Low for tracking, information storage and transmission and operational procedures
SENSITIVITY TO CHANGE	Medium	Low	High
PRACTICE AND PERFORMANCE CRITERIA	Simple and objective for psychomotor task. Difficult and subjective for others. Inputs - readily obtainable.	Objective criteria and easy practice for all tasks. Inputs - readily obtainable.	Subjective criteria and difficult practice. Inputs-complex and dynamic.

Fig. 42 - Relative Comparison of AN/TSQ-47 Tasks in Terms of Proficiency Requirements.

(e) Follow-up and changes in planning

(f) Initiation of emèrgency instructions or procedures

(g) ECCM (voice and radar).

H. MAINTENANCE SHELTER

The design specifications for both the field maintenance shelter and the rear echelon facility will be prepared during subsequent portions of the AN/TSQ-47 program. The maintenance shelter presents some special problems which result from the nature of the equipment to be serviced and the current maintenance capabilities of the Air Force Communications Service. The user squadrons currently have no capability (qualified personnel or equipment) for maintaining either the microwave relay equipment or the cryptographic units.

The remaining effort leading to complete maintenance facilities must await the delineation of a maintenance philosophy by cognizant Air Force personnel. Once such a philosophy has been established, it will be possible to review test equipments, maintenance facilities, and personnel requirements, and recommend a maintenance package for the AN/TSQ-47. The maintenance philosophy must include such items as: the personnel (numbers and skill levels) to be used at each echelon; the levels of malfunction isolation and/or repair to be carried out at each echelon; the degree of standardization and modularization to be employed in equipment construction; the philosophy of preventive vs. corrective maintenance; and the relative merits of a "replacement" vs. a "repair" maintenance approach.

These problems and many other pertinent items will be resolved by the Air Force in the near future, and the work on maintenance facilities should proceed from that point.

I. CONTROLLER-AID SHELTER

The controller-aid shelter is currently under study and development by the AVCO corporation. Their program is essentially a two-part investigation, the first phase dealing with equipment feasibility and hardware development and the second concerned with a controller task analysis study to determine the ways in which controller-aids may change the tasks and functions of controllers. As currently conceived, the controller-aid shelter will be a compact-path computer and automatic tracking system.

The human factors evaluation of this semi-automatic capability must await the results of the AVCO study, since the decision as to whether to include the shelter in the AN/TSQ-47 will have to be made upon the joint bases of (1) the reduction in controller loads, and (2) the complexity of the hardware required to attain the desired capability.

Further effort on this shelter will also be a part of a subsequent program.

IV. COMMON DESIGN CRITERIA

A. INTRODUCTION

Although the equipment for the AN/TSQ-47 is to be "off the shelf" wherever possible, many modifications will no doubt be required in order to achieve an integrated system. The purpose of this section is to anticipate the kinds of modifications that may be required, and to specify human engineering guidelines for use during the modification of "off the shelf" equipment.

B. GENERAL CONSIDERATIONS

1. Standardization

   a. Insofar as possible, selection of components, marking, coding, labeling, and arrangement schemes (equipment layout) should be standard for all system equipment. Where equipment units are manufactured by different contractors, uniformity should be accomplished by agreement with the procuring authority.

2. Fail-Safe Design

   a. All reasonable effort should be directed toward the achievement of a fail-safe design in those areas where high reliability cannot be expected and the consequences of failure will be severe, such as destruction of equipment or injury to personnel.

3. Designation of Functional Areas

   a. Whenever it is desired to set apart, for purposes of ready identification, distinct, noncritical functional areas (those not associated with emergency operation), these areas should be outlined by black lines approximately 1/16 inch wide.

b. Functional areas of emergency or extremely critical operations should be set apart by a 3/16 inch red border. Red should be in conformance with Color No. 31136, Federal Standard 595.

4. Fail-Safe Operation

a. Whenever feasible, displays should be so designed that the failure of the display and/or display circuitry should be immediately and readily apparent to the operator.

b. Failure of display circuitry should not cause a failure in the equipment associated with the display.

C. LABELING

1. Controls and Displays

a. Each control and display should be identified as to function.

b. Labels should appear either on or immediately adjacent to (preferably above) the controls and displays to be identified and should be so located as to preclude association of a label with the wrong control or display.

c. The location of labels in relation to controls and displays should be consistent on all system equipment.

d. Labels should be brief. Although the nomenclature should clearly indicate the function being displayed or controlled, highly similar names should be avoided. Abbreviations, where required, should be common or meaningful and should conform with MIL-Std-12A and ANA Bulletin 261.

e. Lettering on the panels should be black, Color No. 37038, Fed. Std. 595.

f. Capital letters should be used in preference to lower case.

g. Abstract symbols (squares, Greek Alphabet, etc.) would not be used as labels. Common meaningful symbols such as the per cent sign, plus sign, etc., are acceptable.

2. Units

a. Wherever possible, the outside covering of manufactured parts such as resistors, condensers, and tubes, should be stamped or coded with relevant information concerning electrical characteristics of the part.

b. Where space permits, terminals should be labeled with the same code symbol as the wire attached to it.

c. Labels should be etched or embossed into the component or chassis rather than merely printed or stamped on the surface. If surface labels must be used; decals, silk-screened or stamped labels are preferable to stenciled labels.

d. Labels should not be hidden by units and parts. For example, labels on the chassis should not be placed under the parts which they identify.

e. Bill of material or maintenance nomenclature should not be placed on the front of the panel, but rather behind the control panel where possible in order to facilitate trouble shooting and maintenance.

D. DISPLAYS

1. Cathode-Ray Tubes

a. Since interpretation of scopes requires a high degree of skill, and necessary skills may be limited, the use of scopes should be minimized.

b. The display should resolve as much detail as is required for adequate interpretation of the displayed information.

c. The brightness contrast relationship between the signal and background should be sufficiently high to afford good visibility.

d. A 16-inch viewing distance should be used whenever practical. Where periods of scope observation are short and where it is important that dim signals be detected, the recommended 16-inch viewing distance can be reduced to 10 to 12 inches.

e. Whenever possible, the scope face should be in a plane which is perpendicular to the operator's normal line of sight.

f. The ambient illumination in the CRT area should be sufficiently high for other visual functions (setting controls, reading instruments, maintenance, etc.) but should not interfere with the visibility of the signals on the CRT.

g. Ambient room illumination should not contribute more than 25% of the screen brightness through diffuse reflection and phosphor excitation.

h. Room illumination may be sufficiently high for other visual tasks if the scopes are adequately hooded or shielded from the light.

i. Surfaces immediately adjacent to the scope should be in a brightness range from equal to the brightness of the screen to 10% of this brightness. No light sources brighter than the radar signals should be in the immediate surround.

j. Surfaces immediately adjacent to the scope should have a dull matte finish. The reflectances of the surfaces should be such that the resultant brightnesses are consistent with the recommendations above.

k. The design of scales and other devices used to get quantitative data from the display should be such as to maximize accuracy and speed.

E. CONTROLS

1. Use of Controls

a. Controls should be distributed so that no one limb is overburdened.

b. Control movements should be in the directions that conform with population stereotypes.

c. For high precision over a wide range of adjustments, multi-rotation controls should be used.

d. Adjustments should be divided into discrete steps when possible, using detent controls.

e. With the exception of standard valve controls, rotary controls should always turn to the right (clockwise) to increase, left (counterclockwise) to decrease. Controls should be so labeled by means of arrows and appropriate legends.

f. Valve controls should be provided with a double-ended arrow with "open" or "close" at or beside the tip of each arrow.

2. <u>Prevention of Accidental Activation</u>

a. Controls requiring protection should be located and oriented so that the operator is not likely to hit or move them accidentally in the normal sequence of control movements Controls requiring protection are particularly those whose inadvertent operation can result in equipment or personnel hazards or in delays, and possibly those which are "hidden" and whose inadvertent operation would cause locating difficulty and time consuming adjustment difficulties.

b. Any method of protecting a control should not preclude its being operated quickly when desired.

c. Recesses, shields, or physical barriers placed around the control can be used as protective methods.

d. Covers or guards should not be used if the control is used frequently unless the guard can be locked out of position.

e. Interlocks can be provided so that extra movement (e.g., a side movement out of a detent position, a pull-to-engage clutch, etc.) or the prior operation of a related or a locking control is required

f. Resistance, friction and spring loading, viscous damping, or inertia can be built into the control so that definite and/or sustained effort is required to actuate it.

F. MAINTAINABILITY

1. Unitization of Equipment and Functions

a. Unless structurally or functionally not feasible, all equipment should be designed in such a manner that rapid and easy removal and replacement of malfunctioning units can be accomplished by one operator.

b. Unitization of system equipment should be carried at least to the level of the diagnostic capability of the test equipment and/or operator. That is, if the capability exists to isolate a malfunction, then that component or part of the assembly should be packaged so as to be quickly and easily removed and replaced.

c. Where possible, units serving the same function in different applications should be designed to be interchangeable.

d. The number of inputs to and outputs from each unit should be kept to a minimum by grouping of functions so that a minimum of criss-crossing of signals between units is required.

e. Where consistent with maintenance concepts, functions should be so unitized that it is possible to check and adjust each unit separately.

2. Location of Components

a. Parts should be mounted in an orderly array on a "two dimensional" surface and not "stacked" one on another, i.e., the lower layer not supporting the upper layer of units.

b. Large manufactured parts which are difficult to remove should be so mounted that they do not prevent convenient access to other parts.

c. Components should be placed so that:

(1) There is sufficient space to use test equipment and other required tools without difficulty or hazard.

(2) Structural members of the units and chassis do not prevent access to components.

(3) All throwaway assemblies or parts are accessible without removal of other components.

(4) Delicate components should be located or guarded so that they will not be damaged while the unit is being handled or worked on.

(5) If screwdriver adjustments must be made blind, mechanical guides should be provided, or the screws mounted so that the screwdriver will not fall out of line.

d. Sensitive adjustments should be located or guarded so that they will not be disturbed.

e. Internal controls should not be located close to dangerous voltages.

f. Components of the same or similar form, but of different functional properties, should be mounted with a standard orientation throughout the unit, but should be readily identifiable, and not physically interchangeable.

3. <u>Size and Weight of Units</u>

a. When possible, units should be small and light enough for one man to handle and carry, i. e., weight of removable units should be held below 45 pounds. Units in excess of 45 pounds should have provision for two-men lift where the lifting height is not in excess of five feet and where the total weight is not in excess of 90 pounds. Units weighing over 90 pounds should have provision for mechanical or power lift.

b. All units weighing 45 pounds or more should be prominently labeled with their weight.

4. Attachment of Components

a. Only interconnecting wiring and structural members should be permanently attached to the unit chassis. All parts should be mounted on,or as subassemblies.

b. All units designed to be removed and replaced should be provided with handles or other suitable provision made for grasping, handling, and carrying.

c. Whenever possible, handles or grasp areas should be located over the center of gravity of the unit so that when the unit is lifted it does not swing or tilt.

d. Handles which must be grasped firmly should be at least four and one-half inches in length and two inches in depth, assuming a bare hand.

e. Handles and grasp areas should be located so that at least two inches of clearance from obstructions is provided during handling.

5. Rests and Stands

a. Rests and stands on which units can be placed should be provided. Where feasible, rests or stands should incorporate provisions for test equipment tools and manuals. Where design requirements permit, the rests and stands should be a part of the basic chassis.

b. Irregular, fragile, or awkward extensions, such as cables, wave guides, hoses, etc., should be easily removable before the unit is handled.

6. Covers and Cases

a. The proper orientation of a unit within its case should be made obvious, either through design of the case or by means of appropriate labels.

b. Where possible, cases should be designed to lift off units rather than units lifted out of cases.

c. Cases should be made larger than the units they cover so that wires and other components are not likely to be damaged when the cases are put on or taken off.

d. Where feasible, guides, tracks, and stops should be provided to facilitate handling and to prevent damage to units and components.

e. Where space permits, hinged covers should be used to reduce the number of fasteners required.

f. The method of opening a cover should be obvious. If it is not obvious from the construction of the cover itself, an instruction plate should be permanently attached to the outside of the cover.

g. It should be obvious when a cover is in place but not secured.

h Sharp edges and corners on cases and covers should be avoided.

7. Lubrication

a. Units containing mechanical components should not require lubrication, or there should be provision for lubrication without disassembly.

b When lubrication is required, the type lubricant to be used and the frequency of lubrication should be specified by a label at or near the lube port.

8. Mounting of Units

a. A minimum number of screws or bolts should be used for unit installation.

b. Whenever possible, identical screw and bolt heads should be used. This is to permit various panels and components to be removed with one type of tool.

c. Field removable assemblies and units should be replaceable with nothing more than common hand tools.

d. Units which are frequently pulled out of their installed position for checking should be mounted on roll-out racks, slides, or hinges.

e. Guide pins or their equivalent should be provided on units for alignment during mounting.

f. Limit stops should be provided on roll-out racks and drawers. Over-ride of these limit stops should be conveniently accomplished.

g. Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit should have large enough holes for passage of the screw without perfect alignment.

h. All interchangeable units should be coded (keyed) so that it is physically impossible to insert a wrong unit. Units should also be coded (color, labels, etc.,) so as to indicate the correct unit and its orientation for replacement.

i Units should be removable along a straight or slightly curved line rather than through an angle.

j. Units should be laid out so that a minimum of place-to-place movement is required of the operator during checkout.

G. ACCESSIBILITY

1. General Access

a. Hinged doors or covers with captive quick-opening fasteners should be provided wherever possible.

b. If a hinged access or quick-opening fastener will not meet stress, pressurization, shielding, or safety requirements, the minimum number of the largest screws consistent with these requirements should be used.

c. All access covers which are not completely removable should be self-supporting in the open position.

d. Units should not be placed in recesses, behind, or under stress members, floor boards, seats, hoses, pipes, or other items which are difficult to remove.

e. If instructions applying to a covered unit are lettered on a hinged door, the lettering should be properly oriented for reading when the door is open.

f. Sliding, rotating, or hinged units to which rear access is required should be free to open or rotate their full distance and remain in the "open" position without being supported by hand.

g. Check points, adjustment points, cable end connectors, and labels should be accessible and face the maintenance man where possible.

h. Bulkheads, brackets, other units, etc., should not interfere with removal or opening of covers of units within which work must be done.

i. Unless a unit is completely self-checking, provision should be made for the checking operation of that unit in the operating condition and without the use of special rigs and harnesses.

j. Where visual access only is required, the following practices should be followed in order of preference:

(1) An opening with no cover should be used unless this is likely to degrade system performance.

(2) A plastic window should be used if dirt, moisture, or other foreign materials are a problem.

(3) A break-resistant glass window should be used if physical wear, heat or contact with solvents will cause optical deterioration.

(4) A quick-opening metal cover should be used if glass will not meet stress or other requirements.

k. Where access for tools, test leads, and service equipment only is required, the following practices should be followed, in order of preference:

(1) An opening with no cover should be used unless this is likely to degrade system performance.

(2) A sliding or hinged cap should be used if dirt, moisture, or other foreign materials are a problem.

(3) A quick-opening cover plate should be used if a cap will not meet stress requirements.

2. Apertures

a. Openings and work spaces provided for adjusting and handling units should be ample to permit the required activity, and where possible to permit adequate view of the components being manipulated. A larger opening must be provided if the operator or maintenance man will be wearing gloves, the degree of enlargement depending on glove thickness.

b. Units should be located and mounted so that access to them may be achieved without danger to personnel from electrical charge, heat, sharp edges and points, moving parts, chemical contamination, or other hazardous sources.

3. Interposition

a. Removal of any replaceable unit should require opening or removal of a minimum number of covers or panels (preferably one).

b. Wherever possible, units should be located so that no other equipment must be removed to gain access.

c. When necessary to place one unit behind another, the unit requiring most frequent access should be most accessible to the user.

d. Access to units maintained by one operator should not require removal of equipment maintained by a second operator, particularly when such equipment is of critical nature, the maintenance of which requires highly specialized skill.

H. CONDUCTORS, CONNECTORS, AND FASTENERS

1. Conductors

a. Conductors should be bound into cables and held by means of lacing twine or other acceptable means. Long conductors or cables, internal to equipment, should be secured to the chassis by cable clamps.

b. Cables should be long enough that each functioning unit can be checked in a convenient place. (Extension cables should be provided where this is not feasible).

c. If it is necessary to route cables and wires through holes in metal partitions, they should be protected from mechanical damage by grommets or other acceptable means. Routing of electrical cables below fluid lines or near high temperature sources should be avoided.

d Cables should be routed so that:

(1) They cannot be pinched by doors, lids, etc.

(2) They cannot be walked on or used for handholds.

(3) They are accessible for inspection and repair.

(4) They need not be bent or twisted sharply or repeatedly.

(5) Cabinet input and output cables, with the exception of test cables, should not terminate on the control-display surfaces of cabinets.

(6) If test cables terminate on control and display panels, the test receptacles should be so located that the associated cables will not interfere with controls and displays.

e. Cables containing individually insulated conductors with a common sheath should be coded as specified in ARDCM 80-5.

2. Connectors

a. Plugs requiring no more than one turn or other quick disconnect plugs should be used whenever feasible.

b. Connectors should be located far enough apart that they can be grasped firmly for connection and disconnection. Space required will depend upon the size and shape of the plug.

c. The rear of plug connectors should be accessible for test and service, except where potting, sealing, or other considerations preclude this.

d. Plugs or receptacles should be provided with alignment pins or other alignment devices. Aligning pins on plugs should project beyond the electrical pins.

e. Where a reasonable possibility exists for unintentional interchange of connectors, plugs will be so designed that it is impossible to insert the wrong plug in a receptacle.

f. Plugs or receptacles should be arranged so that the alignment pins are oriented in the same direction throughout the system.

g. Connecting plugs and receptacles should be identified by color, or shape, or other acceptable means.

h. Plugs and receptacles should have painted stripes, arrows, or other indications to show the position of aligning pins for proper insertion.

i. The system should be designed so that all "hot" contacts are socket contacts.

3. Fasteners and Mounting Bolts

a. Maximum use should be made of tongue-and-slot-catches to minimize the number of fasteners required.

b. The number and diversity of fasteners used should be the minimum commensurate with requirements for stress, bonding, etc.

c. Where feasible, the same size and type of fasteners should be used for all covers and cases.

d. Captive fasteners should be used where possible.

e. Screws with different threads should be of different sizes.

f. If compatible with stress and load considerations, fasteners for mounting assemblies, subassemblies, etc., should fasten or unfasten in a maximum of one complete turn. If bolts are required, the number of turns required to tighten or loosen them should be minimized.

g. Hand operated fasteners are preferred; those requiring standard hand tools are acceptable; those requiring nonstandard tools should not be used.

h. Bolts requiring high torque should be provided with external grip heads.

i. Captive bolts and nuts should be used in situations where the dropping of these small items into the equipment will cause damage or create a difficult removal problem.

I. TEST POINTS

1. Primary (Operational) Test Points - (Used to isolate malfunctions to a removable subassembly.)

a. Where a unit is not completely self checking in its operational condition, appropriate test points should be provided.

b. Only such primary test points as are necessary to determine that a unit is malfunctioning should be provided.

c. Primary test points should be so located and coded as to be readily distinguished from secondary test points.

d. Where feasible, primary test points should be grouped in a line or matrix reflecting the sequence of tests to be made.

e. Primary test points used in adjusting the unit should be located close to the controls and displays also used in the adjustment.

2. Secondary (Maintenance) Test Points - (Used to isolate a malfunctioning detail part within a subassembly after the subassembly has been removed from the component or major assembly).

a. Where feasible, and when not in conflict with other requirements, a secondary test point should be supplied at the input and output of each part or throwaway component.

b. Sufficient test points should be provided so that it will not be necessary to remove subassemblies in trouble shooting.

c. Each test point should be so marked as to be readily identifiable.

J. EQUIPMENT COLORS

1. Shelters and Trailers - (Those shelters and trailers which house equipment and personnel directly associated with operating or maintaining the direct mission of the system).

a. Operational equipment shelters and trailers should have the following color schemes:

(1) Floors: Color 36440-Gray, Federal Standard 595.

(2) Walls: Color 34670-Green, Federal Standard 595.

(3) Ceilings: Color 37886-White, Federal Standard 595.

(4) Storage Cabinets and equipment racks: Color 24300-Green, Federal Standard 595.

b. Pipes, conduit, etc., should be painted the same color as the surface to which they are attached.

2. Consoles and Panels

a. Operational equipment consoles and panels should have the following color schemes:

(1) Console Exterior: Color 24300 - Green, Federal Standard 595.

(2) Console Interior: Color 2662 - Gray, Federal Standard 595 (Used only where maintenance and trouble shooting are required within the console).

(3) Panels: Color 36492 - Gray, Federal Standard 595.

(4) Panel Lettering: Color 37038 - Black, Federal Standard 595.

K. WORKSPACE CHARACTERISTICS

1. Anthropometry

a. The location, size, etc , of equipment should be such that the equipment will be easily operated and maintained by at least the 5th to 95th percentile group of the Air Force population. Consideration should be given to possible environmental conditions which may require personal protective encumbrances and make "normal" operation difficult. The following dimensions should make equipment suitable for 90% of the population. It should be noted that these dimensions must be altered to allow for encumbrances.

Minimum overhead height for standing position -	73 inches.
Maximum allowable overhead reach -	76 inches.
Minimum height required for crawling -	31 inches.
Maximum allowable depth of reach -	23 inches.
Minimum dimension for passing body width -	20 inches.
Minimum dimension for passing body thickness -	13 inches.

2. Standing Operations

a. Ideally, visual displays on vertical panels should be mounted in an area no higher than 70 inches and no lower than 40 inches above the standing surface. Precise reading indicators and important controls should be placed in an area no higher than 64 inches and no lower than 48 inches above the standing surface.

b. Insofar as possible, controls should be mounted on vertical panels in an area no higher than 70 inches and no lower than 30 inches above the standing surface. The preferred area for precision controls or those operated frequently is between 40 and 55 inches from the standing surface.

3. Seated Operations

a. When continuous monitoring is required of a seated operator, controls and displays should be mounted on a sloped console surface

b. For normal seated operations, the slope of the control-display panel surface should begin at 30 inches from the floor with the over-all console height not exceeding 48 inches. (This will allow the operator's direct line of slight to extend beyond the console).

c. If the operator's direct line of sight is not required to extend beyond the console, the over-all console height may extend to, but not exceed, 65 inches from the floor. In such situations the upper panel surface should be inclined from the vertical toward the operator.

d. Arm rests should be provided at all consoles. These rests should either be a part of the console or a part of the operator's chair.

e. Console arm supports should provide at least eight inches and preferably 12 inches of resting surface projecting horizontally across the front of the console.

f. Arm rests integral with the operator's chair should be a minimum of two inches wide by 10 inches long.

g. If the operator must record data, a writing surface 12 inches in depth is recommended.

h. Knee and foot room beneath the panel surfaces should be provided. The minimum dimensions are: 25 inches high by 20 inches wide by 18 inches deep.

i. All cabinets, consoles, and work surfaces requiring that an operator stand or sit in close proximity to their front surfaces should contain a kick space four inches deep by four inches high at the base.

j. Handles on cabinets and consoles should be recessed when practical to eliminate projections on the cabinet surfaces.

k. Sufficient room to accommodate the hand should be provided in the grasping of all handles.

4. Work Surfaces

a. Work benches and other work surfaces provided for standing operations should be 36 inches above the floor.

b. Desk tops, writing tables, and other work surfaces provided for seated operation should be 30 inches above the floor.

c. Convenient work surfaces to support job instruction manuals, worksheets, etc., should be provided where necessary for standing operators of control-display panels.

L. HAZARDS AND SAFETY

1. General Safety Considerations - (Representative items).

a. It should be insured that conspicuous placards are mounted adjacent to high voltage, extremely cold, very hot, etc., equipment.

b. Operations of switches or controls which initiate hazardous operations such as ignition, crane moving, etc., should require the prior operation of a related or locking control. Where practicable, the critical position of such controls should activate a warning device in the affected area.

c. A hazard alerting device should be provided to warn personnel of impending or existing hazards (i.e., fire, presence of combustible or asphyxiating gas, radiation, etc.).

d. Guards should be provided on all moving parts of machinery and transmission equipment, including pulleys, belts, gears, and blades, etc., in which personnel may become injured or entangled.

e. Self-locking or other foolproof devices should be incorporated on elevating stands and work platforms to prevent accidental or inadvertent collapse.

f. Some form of anchor or outriggers should be employed on stands with high centers of gravity.

g. When applicable, the center of gravity of equipment should be distinctly marked.

h. Handrails should be provided on platforms, stairs, and around floor openings or wherever personnel may fall from an elevation.

i. A safety bar or chain should be attached across stair or step openings on a platform to prevent falling.

j. Automatic shut-off devices should be provided on fuel service equipment to prevent overflow and spillage.

k. Portable hand-operated fire extinguishers should be provided in areas where fire hazards exist or may be created.

l. All emergency doors and exits should be constructed so that they are readily accessible, unobstructed and quick opening. Design should be such that the door or hatch can be opened by a single motion of hand or foot.

m. Eye baths, showers and other first aid equipment should be readily available in areas where toxic materials are handled.

n. Provision should be made for rapid neutralization or flushing of harmful materials spilled on equipment or personnel.

o. Areas of operation or maintenance where special protective clothing, tools, or equipment such as insulated shoes, nonsparking tools, gloves or suits, etc., are necessary, should be specifically identified; such items should be procured along with system hardware.

p. "No Step" markings should be incorporated where applicable.

q. The weight capacity should be indicated on stands, hoists, lifts, jacks, and similar weight-bearing equipment to prevent overloading.

r. Jacking and hoisting points should be conspicuously and unambiguously identified.

s. Wiring should be routed through plugs and connectors so that removal of a plug or connector does not expose hot leads.

t. All pipe lines, liquid, gas, steam, etc., should be clearly and unambiguously labeled or coded as to contents, pressure, heat or cold, and any specific hazards.

u. Adequate illumination should be provided in all areas. Work areas should be illuminated by at least 25 foot candles.

v. Provision should be made for skid-proof flooring and stair or step treads.

w. Clearance for fingers should be considered in the design of telescoping steps or ladders.

M. SUPPLEMENTARY DOCUMENTS

The following technical reports, publications, and documents, will serve as supplementary information for those contractors who desire source references.

1. <u>Technical Reports</u>

a. WADC TR 52-204 Handbook of Acoustic Noise Control.

b. WADC TR 52-321 Anthropometry of Flying Personnel.

c. WADC TR 54-520 Anthropometry of Working Positions.

d. WADC TR 56-171 Layout of Workplaces.

e. WADC TR 56-218 Guide to Design of Electronic Equipment for Maintainability.

f. WADC TR 56-488 Procedures for Including Human Engineering Factors in the Development of Weapon Systems.

2. Documents

a. Federal Standard No. 595--Colors.

b. Air Force Regulations (AFR) 106-3--Hazardous Noise Exposure.

3. Publications

a. Air Force - Navy Aeronautical Bulletin No. 261--Abbreviations and Contractions, Approved List of.

b. AFSC Handbook, AFSCM 80-3--Handbook of Instructions for Aerospace Personnel Subsystem Designers.

c. ARDC Handbook, ARDCM 80-5--Handbook of Instructions for Ground Equipment Designers.

d. ARDC Handbook, ARDCM 80-6--Handbook of Instructions for Aircraft Ground Support Equipment Designers.

V. FUTURE REQUIREMENTS

The material presented in this report points out some obvious requirements for future human factors effort. The five major operational shelters have been laid out and specified in detail, but the human factors portions of these shelters is not yet completed. It will be necessary, for example, to conduct a complete task analysis for each operator position in order to derive quantitative and qualitative personnel requirements information (QQPRI) and training requirements (TED and TEPI) as set forth in the Air Force Personnel Subsystem Manual 80-3. Such information is prerequisite to further Air Force personnel planning and training and must be available prior to delivery of the system hardware to ensure a staff of component Air Force operators and maintenance technicians. Further human engineering effort will also be needed during fabrication of these five shelters to monitor the man-machine interfaces, evaluate the effects of possible trade-offs, and make recommendations to cover any aspects not included in this report of the specifications.

Much additional effort will have to be focused on the other shelters which will eventually become part of the AN/TSQ-47 system. It will be necessary to develop a complete set of functional-operational requirements for the Proficiency Shelter and then to translate these into equipment specifications. The Maintenance Shelter must go through the same stages, beginning with the derivation of a maintenance philosophy and ultimately resulting in the specification of a shelter and its component test equipments.

The Controller-aid Shelter presents a somewhat different problem in that the requirements are more fluid and therefore will require a highly integrated effort by both human factors and engineering personnel. The human factors specialists will have to examine controller tasks with a view towards selecting those tasks or informational components which can and should be made semi-automatic. Engineering personnel can then examine these task components and determine the engineering feasibility of automating them. This process will probably be repeated several times until the best compromise solution is arrived at. This should consist of equipment components which will meet all system and user requirements (e.g., size, mobility, cost, availability, etc.) and still result in the greatest possible reduction of the controllers' task load.

APPENDIX

PROJECT MANAGEMENT

MANPOWER

The AN/TSQ-47 human engineering effort was carried out under Contract Number AF 19(604)-7990, which originally called for a six-month effort and was later extended for an additional six-month period. During the first six-month period Mr. George Grant and Mr. Stephen H. Gates were assigned to the project full-time and were located at the Control Sciences Laboratory, Ft. Dawes, Winthrop, Mass. Mr. Grant served as Project Director during that time. The status of the system at the end of that period was described in an HRB-Singer Scientific Report, AFCRL-944, dated 1 October 1961.

Mr. Gates was the on-site Project Supervisor during the second six-month period. During that time he was assisted at Fort Dawes by Mr. Robert B. King and by Mr. Grant who was assigned to the project on a part-time basis.

Mr. Thomas E. Selby, an air traffic control specialist, served as a consultant during the entire program. The man-hours expended on this contract are shown below.

Name	Title	No. of Hours	Role
Mr. Stephen H. Gates	Senior Psychologist	2040	Technical effort and project supervisor
Mr. George Grant	Senior Psychologist	1308	Project Director
Mr. Robert B. King	Junior Psychologist	1280	Technical effort
Mr. John Rigone	Project Administrator	148	Project Administration
Mr. Thomas E. Selby	Senior Airways Operations Specialist	151	Technical Consultant
Dr. Robert E. Stover	Mgr. Human Factors Section	168	Project Management
Publications Personnel		270	Preparation of reports

TRAVEL

A considerable amount of travel was required during the course of this contract. In addition to travel between Ft. Dawes and State College, Pa., for liaison and report preparation, project personnel visited the following installations:

Agency	Location	Purpose of Visit
3rd Mobile Squadron, AFCE	Tinker AFB, Oklahoma	Discussion with operational and maintenance personnel, review of shortcomings of the original "4-wheel" system, preparation of operational requirements.
Federal Aviation Agency	Norman, Oklahoma	Collection of information about selection, training, and proficiency measurement for air traffic controllers.
Hq. Air Force Communications Service	Scott AFB, Illinois	Discussion of operational requirements and maintenance philosophies.
Avco-Crosley Corp.	Cincinnati, Ohio	Discussion of Controller-Aid shelter.
Cornell Aeronautical Lab.	Buffalo, New York	Discussion of human capabilities and limitations in air traffic control.
Airborne Instruments Lab.	Melville, New York	Preparation of information flow and task analyses for AN/TSQ-47.
Alpha Corporation	Richardson, Texas	Discussions on the communications shelter.
Air Force Security Service	San Antonio, Texas	Discussion of requirements for operation

		and maintenance of cryptographic equipment.
Radio Corporation of America	Camden, New Jersey	Discussions on the search radar shelter.
U.S. Naval Training Service Center	Port Washington, N.Y.	Discussions on principles and techniques of proficiency measurement and evaluation.

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